AD-A013 632

THE DYNAMICS OF NATURAL CLIMATIC CHANGE

John Imbrie, et al

Brown University

Prepared for:

Air Force Office of Scientific Research
Advanced Research Projects Agency

17 July 1975

237115

THIS DOCUMENT: FINAL REPORT

CONTRACT TITLE: THE DYNAMICS OF NATURAL CLIMATIC CHANGE

CONTRACTOR: Brown University, Providence, R.I.

CONTRACT DATE: 1973 December 15

EXPIRATION DATE: 1974 December 14

CONTRACT AMOUNT: $98,230

CONTRACT NUMBER: F44620-73-C-0021

SPONSORED BY: Advanced Research Projects Agency, ARPA Order 2299

PROGRAM CODE: 3F10

PRINCIPAL INVESTIGATOR: John Imbrie (Phone: 401-863-3196)

CO-INVESTIGATORS: R. K. Matthews (Phone: 401-863-3339)

Thompson Webb III (Phone 401-863-3338)

PROGRAM MANAGER: Joseph A. Burnett, Director, Grant and Contract

Services, Brown University (Phone: 401-863-2778)

DATE: 17 July 1975

- 1 -

SECURITY CLASSIFICATION OF THIS PAGE (When Date Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFOSR - TR - 75 - 1076	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Dynamics of Natural Climatic Change		5. TYPE OF REPORT & PERIOD COVERED Final 6/15/74 - 12/15/74
		6. PERFORMING ORG. REPORT NUMBER Final Report
7. AUTHOR(s) John Imbrie, R. K. Matthews, Thompson Webb III		8. CONTRACT OR GRANT NUMBER(s) F44620-73-C-0021
9. PERFORMING ORGANIZATION NAME AND ADDRESS Brown University Department of Geological Sciences Providence, R. I. 02912		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 64706E A02299
11. CONTROLLING OFFICE NAME AND ADDRESS Advanced Research Projects Agency/IPT 1400 Wilson Boulevard Arlington, VA. 22209		12. REPORT DATE 17 July 1975
		13. NUMBER OF PAGES 82
14. MONITORING AGENCY NAME & ADDRESS(If different from Controlling Office) Air Force Office of Scientific Research/NP 1400 Wilson Boulevard Arlington, VA. 22209		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

climate	climate models	transfer functions
climatic change	palynology	
paleoclimatology	sea-level dynamics	
marine pollen	Soviet paleoclimatology	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This document summarizes the results of the ARPA Paleoclimate Project at Brown, with emphasis on work accomplished during the period 15 June 1974 through 15 December 1974. These results include: (1) completion of a numerical experiment on ice-age climate in cooperation with the RAND Climate Dynamics Project 1; (2) organization of a data-exchange program with the Soviet Union as part of Working Group VIII of the US-USSR Bilateral Agreement on

DD FORM 1473   1 JAN 73   EDITION OF 1 NOV 65 IS OBSOLETE

20.

the Environment; (3) formation and analysis of a data bank for pollen data; (4) analysis of the phasing of changes in oceanic circulation and changes in nearby climate and vegetation patterns on land, by means of a simultaneous study of pollen and planktonic fossils in deep-sea cores; (5) completion of a review and critique of transfer-function methodology; and (6) documentation of sea-level dynamics during the interval 60,000 - 250,000 YBP.

Standard Distribution List for Historical Climatology
Technical Reports, Etc for AFOSR/NP Contracts
and Grants

CTIVITY	ADDRESS	TYPE OF REPORTS	NO. OF CYS
dvanced Research Projects gency (ARPA)	Director, ARPA/RPT Attn: Col J. S. Perry 1400 Wilson Boulevard Arlington, VA 22209	Reprints* Semi-Annual Tech* Annual* & Technical Final Reports*	3 3 3 3
ir Force Office of cientific Research	AFOSR/NP Attn: Mr. W. J. Best 1400 Wilson Boulevard Arlington, VA 22209	Quarterly Semi-Annual* Annual* & Technical Final* Reprints*	3 15 15 15 6
niversity of Arizona	Dr. H. C. Fritts University of Arizona Laboratory of Tree-Ring Research Tucson, AZ 85721	Technical Semi-Annual* Annual* Final* Reprints*	1 1 1 1 1
niversity of Wisconsin	Dr. J. E. Kutzbach University of Wisconsin Center for Climatic Research Madison, WI 53706	Technical Semi-Annual* Annual* Final* Reprints*	1 1 1 1 1
cean Atmosphere Research nstitute	Dr. Irving I. Schell Ocean Atmosphere Research Institute Cambridge, MA 02138	Technical Semi-Annual* Annual* Final* Reprints*	1 1 1 1 1
&D Associates	Dr. Leona Libby R&D Associates PO Box 3580 Santa Monica, CA 90403	Technical Reprints* Semi-Annual* Annual* Final*	1 1 1 1 1
niversity of Illinois	Dr. Y. Ogura University of Illinois Laboratory of Atmospheric Research Urbana, IL 61801	Technical Semi-Annual* Annual* Final* Reprints*	1 1 1 1 1
rown University	Dr. John Imbrie Brown University Geological Sciences Providence, RI 02912	Technical Semi-Annual* Annual* Final* Reprints*	1 1 1 1 1

) Form 1473 required for Annual, Semi-Annual, Final, and Reprints.

niversity of Arizona	Professor W. D. Sellers	Reprints*	1
	University of Arizona	Semi-Annual Tech	1
	Institute of Atmospheric Physics	Annual*	1
	Tucson, AZ 85721	Final*	1
ational Academy of ciences	Division of Earth Sciences	Reprints*	1
	National Academy of Sciences	Semi-Annual	1
	Attn: Dr. N. S. Santeford, Jr.	Annual*	1
	Washington, DC 20418	Final*	1
systems, Science and oftware	Dr. W. G. England	Reprints*	1
	Systems, Science and Software	Semi-Annual	1
	La Jolla, CA 92037	Annual*	1
	(PO Box 1620)	Final*	1
Iniversity of Washington	Dr. Max D. Coon	Reprints*	1
	University of Washington	Semi-Annual	1
	Division of Marine Resources	Annual*	1
	Seattle, WA 98195	Final*	1

2

CONTENTS

THE DYNAMICS OF NATURAL CLIMATIC CHANGE:

Final Report

III.   Summary of Results

In previous documents, especially the Semi-Annual Technical Reports No. 2 and 3 submitted in June, 1974, investigators on the ARPA Climate Dynamics Project at Brown have reported in detail their progress towards our stated objectives.   In this Final Report, it seems appropriate to review our major accomplishments, and to stress the general impact of our work, beyond the individual papers cited in earlier reports and listed below.   Six major accomplishments can be cited:

1.   Completion of the first ARPA-CLIMAP 18,000 YBP numerical climate-simulation experiment.   This experiment, the concept and design of which originated in discussions among ARPA investigators at Brown and at RAND, was carried out in a unique enterprise which involved more than 100 people; a dozen or more institutions; and fiscal support both by ARPA and by the IDOE/CLIMAP project. ARPA's contribution at Brown was the funding of part of the work of the three principal investigators, whose efforts were central to the experiment.   Its contribution through RAND involved the support of the RAND General Circulation Model.

This experiment marks a turning point in the study of the dynamics of long-term climatic change.   For the first time a substantial data base was gathered (mainly under the CLIMAP project) to fix the sea-surface temperature pattern during an ice age.   This input, together with ice-margin and sea-level data,

form the boundary conditions for the running of an atmospheric model. The model then calculates many elements of the atmospheric circulation which maintained the ice-age climate. The experimental aspect of the project lies in the fact that ARPA scientists at Brown gathered independent data on the actual 18,000 BP response of the atmosphere at point locations over the continent. By comparing the model calculations with independent geological observations, we can in principle confirm or deny the accuracy of the atmospheric model -- and thus get at two fundamental problems: verification of the explanatory power of numerical models of the atmosphere; and discovery of atmospheric mechanisms which maintain our planet's climate in other modes than are known from the past century of instrumental observations.

Thus, in our opinion, the results of the Brown ARPA Climate Dynamics project have a significance beyond that which might appear in a simple listing of our publications. At a conference held at Brown on March 26, 1975, 25 scientists gathered to observe the confrontation of geological data with the calculations of the RAND model. The main results were three: First, the surface temperature calculations of the model appear to be confirmed by geological observations (See Appendix A). Second, the average air-temperature change over the lands during the 18,000 BP ice-age N. Hemisphere summer was about -6.5°C. The

importance of this figure lies in its small magnitude. Consider-
ing that the Northern Hemisphere during the last century has
oscillated through a range of $1.0^{\circ}C$ (annual mean values), the
surprise is that an ice-age anomaly should be so small. The
general conclusion to be made is that the Earth's climate should
be considered in rather sensitive balance. Third, the model
precipitation anomaly, at least in its geographic pattern, is
not confirmed by geological observation.

2. The principal investigator of the Brown ARPA Project
participated during June 1974 in a two-week session, held in the
USSR, of Working Group VIII of the US-USSR Bilateral Agreement
on the Environment. As a result of these negotiations, a bi-
lateral program of paleoclimatic data exchange was initiated
(See Appendix B). The importance of this lies in the need to
obtain (for the running and verification of numerical simula-
tions of past climates) better data on the ice-margins and pol-
len records from the vast interior lands of Russia. Sometime
in 1975, or possibly early 1976, a working conference of paleo-
climatologists is to be held in Moscow. Hopefully, that con-
ference (which is now being finalized by negotiations of NOAA
representatives) will actually materialize. In the meantime,
contacts with M. G. Grosswald at the Institute of Geography in
Moscow have already borne fruit in the form of more accurate
information on the position of ice-margins in Siberia during

the 18,000 BP ice age.

3.   The first units of a computer data bank, in which in-
formation on modern and fossil pollen are stored, have been com-
pleted.   This bank has already been drawn upon for two kinds of
analysis (See Appendix C).   First, the writing of transfer func-
tions which make possible the extraction from pollen data quanti-
tative estimates of past climates.   Second, the preparation for
publication of several synoptic studies of climate-related changes
in vegetation.   Up to now, most pollen-based studies of past cli-
mates have focussed on down-core examination of single sites.
The long-range significance of our program is its emphasis on
the discovery and documentation of synoptic patterns of clima-
tic change.

4.   Our technique of studying simultaneously pollen grains
and planktonic skeletons in the same samples of deep-sea cores
has opened the way for a better look at the dynamics of clima-
tic change.   In a test study off Cape Hatteras, deep-sea cores
were used in this way to obtain evidence on the timing of vege-
tation changes on land compared to the timing of changes in the
position of the Gulf Stream (See Appendix D).   Evidence is that
the oceanic changes here precede changes in the adjacent contin-
ent.   Thus encouraged, ARPA investigators at Brown, in coopera-
tion with palynologists at NYU, began a similar study in cores
off the coast of California, Oregon, and Washington.   Here con-

tinuous vegetation records can be obtained going back about
100,000 years. Again, we are confident that this work will
prove to be a springboard for much future research. On April
25, 1975, a conference of 22 investigators was held at Brown to
consider the opportunities, assess results to date, and encour-
age others to adopt the procedure.

5. Investigators on the Brown ARPA Project have played a
leading role in development of transfer-function techniques by
which geological observations on pollen or marine microfossils
in ancient sediments can be translated into quantitative esti-
mates of climatic variables. Early papers by Imbrie and Kipp
(1971) and Webb and Bryson (1972), which antedated our Project,
initiated a wide and growing effort by many investigators to
employ these techniques to document the climatic history of the
Quaternary. With ARPA support, we have carried on a systematic
analysis of the strengths and weaknesses of transfer function
methodology, examined basic assumptions, and carried out alge-
braic experiments to test the attributes of alternate techni-
ques. One summary paper (See Appendix E) is in press. Another
is in preparation by the same authors.

6. Climatic history without an accurate absolute chronology
is of little value. Absolute dates based on Thorium-growth methods
from fossil reefs on oceanic islands have proved to be the key-
stone block of our knowledge of the chronology of the climatic

history of the past 250,000 years. Again, Brown investigators
played a major role in this area before the ARPA Project here
was funded. During the life of our Project here, attention was
focussed, first, on improving the accuracy of the chronology;
and, second, on extracting information on the rate of change of
sea level, hence on the rate of change of polar ice caps. Major
results on the first objectives have been published (notably in
Bloom et al., 1974) and been reviewed in previous ARPA Reports.
As the Project terminated, eight new Thorium dates led to the
conclusion that the 60,000-year high stand of the sea is not
represented in the Barbados sequence. And the thrust of our work
now shifts to the laborious task of improving the accuracy of
the Th-230 dating method. Major results of the second objective,
previously reported, are that the 125,000-year sea-level high
stand lasted not longer than 5,000 years; and was followed by
a sea level lowering at a rate of 5-10 meters per thousand years.
The dynamics of this portion of the sea-level record are of par-
ticular interest, because the climate today is in many respects
a duplication of planetary conditions obtaining at 125,000 YBP.

IV. REFERENCES

Bloom, A. L., Broecker, W. S., Chappell, J. M. A., Matthews, R. K., and Mesolella, K. J., 1974, Quaternary sea level fluctuations on a tectonic coast: new $^{230}Th/^{234}U$ dates from the Huon Peninsula, New Guinea: Quaternary Research, V. 4, p. 185-205.

Imbrie, J. and Kipp, N. G., 1971, A new micropaleontological method for quantitative paleoclimatology: application to a late Pleistocene Caribbean core: in The Late Cenozoic Glacial Ages, K. Turekian (ed.), p. 71-181.

Webb, T. III and Bryson, R. A., 1972, Late- and Postglacial Climatic Change in the Northern Midwest, USA: Quantitative Estimates Derived from Fossil Pollen Spectra by Multivariate Statistical Analysis: Quaternary Research, V. 2, p. 70-115.

APPENDIX A

PRELIMINARY REPORT OF THE CONFERENCE HELD AT BROWN UNIVERSITY

MARCH 26, 1975

I. PRELIMINARY CONCLUSIONS

A. About model skill.

1. Model surface-level air-temperature anomalies over
land are in accord with generalized geological expectations; and
in the limited number of sites where we can make spot checks,
model values are consistent with proxy information.

2. Model precipitation-anomaly patterns and surface-
wind maps are not consistent with geological information in a
number of areas. This conclusion is in accord with the relatively
low level of model skill in simulating these qualities for today's
world.

B. About improving verification procedures for the next
experiment.

3. First priority should be given to increasing the
accuracy and distribution of data from pollen, marine mineralogy,
loess, and Indian Ocean sediments.

4. Second priority should be given to opportunities for
improving inferences from periglacial features, and for disen-
tangling temperature from precipitation information in snow-line
data.

5. Model readout should include moisture-balance maps,

as this quantity better matches the pollen verification data.

6. Wind-roses at least for selected sites south of the ice sheets should be included in model output.

7. The model used to calculate wind maps at the surface should be augmented.

8. Greater attention should be paid by the geologists to the degree to which a site represents a 500-km-size area, for that is the spatial scale of model response.

C. About the 18K world.

9. From the proxy data assembled for verification we have learned from mineralogy that the trade wind belts shift equatorwards about 5° latitude; and from palynology described several spatial patterns of moisture anomaly.

10. From the combined operation of model-input, model-output, and verification, we are developing a solid basis for defining at least the broad outlines of the surface-temperature anomaly of the sea surface and the surface-air temperature anomaly during the last glacial maximum. From this experiment, e.g. an August sea anomaly of 2.3°C corresponds to an atmospheric anomaly over the ice-free land of about 6°C.

II. A summary of the validation phase of the experiment is provided by Tables 1 and 2 on the following two pages.

Table 1. Geographic distribution of sites and site-clusters for which climatic estimates for 18K were compiled by Webb and Krause.

Region		Temperature Anomaly		Moisture Anomaly	Totals
Continent	Latitude[a]	Annual	July		
N. Amer.	H	2	7	10	19
	L	1	1	4	6
S. Amer.	H	–	–	1	1
	L	1	–	3	4
Europe	H	5	4	5	14
Asia	H	5	5	–	10
	L	1	–	–	1
Australia	H	–	1	–	1
	L	1	–	–	1
Africa	H	1	–	1	2
	L	3	–	5	8
Totals		20[b]	18[c]	29[d]	67

(a)   H = $> 34°$ in N. Hemisphere, $> 26°$ in S. Hemisphere
      L = between 34°N and 26°S

(b)   12 sites from pollen data

(c)   6 sites from pollen data

(d)   mainly pollen data

Table 2. Generalized geologic estimates of maximum-glacial continental climatic-anomaly contained in four well-known summary publications, compared with RAND model calculations.

Geological Estimates				Model Calculations (N. Hem. summer, S. Hem. winter)
Summary Publication	Quantity Estimated	Ref. page	Result (T. decrease in $^{\circ}$C)	
Flint (1971)	Mean annual T in maritime climates at low altitudes and latitudes	4	$3^{\circ} - 6^{\circ}$	$4^{\circ} - 8^{\circ}$ (a)
	Maximum mean annual temperature in continental situations	4	12° or more	14° (g)
	average annual global mean (T)	441	prob. not over 7°	6.4 (b)
	Central Europe (T)	439	$10^{\circ} - 14^{\circ}$	$8^{\circ} - 14^{\circ}$ (c)
West (1968)	Precipitation reduction in British Highlands	206	20%	15% (global average)
	Mean annual T	207	$5^{\circ} - 8^{\circ}$	6.4° (b)
	Global July T	197	$> 4.5^{\circ}$ (h)	6.4° (b)
Emiliani and Flint (1963)	Central Europe (T)	897	$8^{\circ} - 10^{\circ}$	$8^{\circ} - 14^{\circ}$ (c)
	N. Italy (T)	897	9°	10° (d)
	Carpathian Poland	897	13°	9° (e)
Emiliani (1971)	Continental temp. in low latitudes (6°S-27°N)	186	$5^{\circ} - 10^{\circ}$	$5^{\circ} - 7^{\circ}$ (f)

(a) Eastern Coast of S. America north of 22°S. Range along Atlantic African Coast is $3^{\circ} - 9^{\circ}$, with the higher figures at upwelling sites.

(b) Average over both Hemispheres of ice-free land.

(c) Over Europe, latitudes $46^{\circ} - 50^{\circ}$.

(d) Mean of two points representing Italy.

(e) If mtn point to east is averaged = 11.5°

(f) Range of averages of corresponding latitude circles.

(g) Maximum N. Hem. value away from high mtns.

(h) A minimum estimate calculated from an average snowline-lowering of 760 m; lapse rate of 0.6°C per 100 m; and the assumption that precipitation did not change.

B-1

APPENDIX B

B-1

THE FIRST SESSION OF THE WORKING GROUP VIII

ON THE INFLUENCE OF ENVIRONMENTAL CHANGES

ON CLIMATE

10 - 21 June 1974
Leningrad

Leningrad
1974

REPORT OF THE FIRST MEETING OF WORKING GROUP VIII
(INFLUENCE OF ENVIRONMENT CHANGE ON CLIMATE) -
FOR IMPLEMENTATION OF THE AGREEMENT BETWEEN
THE UNITED STATES OF AMERICA AND THE UNION OF SOVIET
SOCIALIST REPUBLICS ON COOPERATION IN THE PROTECTION
OF THE ENVIRONMENT

1. INTRODUCTION

1.1 The first meeting of Working Group VIII was held in Leningrad on June 10-21, 1974, as agreed to at the November 16, 1973 meeting of the Joint Committee. The participants in this meeting from both the U.S. and the USSR are listed in Appendix A. Plenary sessions were held on June 10-12 and June 19-21. Details of the agenda, including subjects and authors of formal presentations, are given in Appendix B.

During the period June 13-18, members of the American delegation visited Soviet institutions and observatories in Moscow, Novosibirsk, Kiev, Crimea and the northern Caucasus. There were also visits to a number of institutions in Leningrad during the first period of the meeting. The institutions visited by the American delegation are listed in Appendix B.

1.2. Working Group VIII, by decision of the Joint Committee, is divided into three projects. To facilitate discussion, the projects have been organized into six subgroups as follows:
Project 1. Joint studies of the effects of changes in the heat balance of the atmosphere on climate.
   a. Subgroup 1 - The influence of changes of solar activity on the climate.
   b. Subgroup 2 - Modelling of the climate.
   c. Subgroup 3 - Assessment of past climates on the basis of the analysis of natural objects and data.
Project 2. Joint studies of the effects of pollution of the atmosphere on climate.
   a. Subgroup 4 - Monitoring atmospheric constituents and assessment of their effects on climate.
   b. Subgroup 5 - The effect of pollution of the upper levels of the atmosphere on climate.

Project 3 (also Subgroup 6). Joint studies of the meteorology and air-sea interaction of polar regions in both hemispheres as they affect the climate of the planet.

There were discussions concerning the need to recommend the reorganization of this Working Group to the Joint Commission. Important considerations for the organization of the Working Group are achieving sufficient disciplinary homogeneity within each project to permit successful collaboration and the recognition of the relationship of this Working Group to other groups established under this and other bilateral and international agreements.

For the latter reason, the work of the Subgroup on polar studies is specifically concerned with problems of climate and not with the broad spectrum of all polar investigations. On the other hand there are aspects of air-sea investigations without which full understanding of the environmental influences on climate cannot be adequately treated.

At the same time, the studies of solar activity on climatic variations use different types of data and analysis and are broader in scope than the work of the other subgroups of Project 1.

For these reasons a recommendation is made to the Joint Committee for reorganizing Working Group VIII. It is realized that this recommendation impacts the interface between the efforts under this bilateral agreement and that on the Study of the World Oceans. It is therefore anticipated that action on this recommendation would require communication between the Joint Committees under the two Agreements.

The following revised structure of Working Group VIII is recommended:

Section 1. Joint studies of the effects of changes of the heat balance of the atmosphere on climate.
    a. Subgroup 1 - Modelling of climate.
    b. Subgroup 2 - Assessment of past changes of the climate on the basis of analysis of natural objects and data.
    c. Subgroup 3 - Interactions of the atmosphere with polar regions and the oceans as they effect climate.

e) The properties of the climatic models and the li-
mits of their applicability may differ depending
on the methods used for parameterization of physical
processes in the atmosphere and the number of the
feedbacks incorporated. It is necessary, therefore,
to formulate the models compatibly to the require-
ments and to evaluate the limits of model appli-
cability with respect to concrete problems.

f) Consideration should be given to the possible de-
sign, performance, analysis and interpretation
of numerical experiments requested by other sub-
groups in order to assess the role of specific
external (man-made) factors effecting the climate.

2.2.2. Data Exchange

Bearing in mind that all the current theories of cli-
mate are approximate, it is necessary to check these theories
against empirical material before applying the models to cal-
culations of future climatic condicions. For this purpose,
short-term seasonal or interannual observations of meteorolo-
gical elements are needed as well as the data on contemporary
climate variations and on climate change in the geological
past. The specification of new observational requirements are
also needed.

2.2.3 Actions Proposed

A joint symposium on climatic modelling may be convened
in Uzbekistan, USSR in 1976.

The United States delegation would like to issue invi-
tations to Soviet scientists to visit the following U.S. insti-
tutions for periods of 6 to 12 months. The invitation is of-
fered to the indicated scientist or a colleague to be agreed
on by both countries.

a) To come to the Geophysical Fluid Dynamics Labora-
tory, National Oceanic and Atmospheric Administra-
tion, Environmental Research Laboratories in Prin-
ceton, N.J. (one or two of the visits to take
place in 1975).

Professor M.I.Budyko - Climate sensitivity and stability.
Professor K.Ya.Kondratiev - Radiation effects of aerosols
Academician G.I.Marchuk - Numerical integration methods
Professor S.S.Zilitinkevich - Coupled ocean-atmosphere models

  b) To come to the National Center for Atmospheric
     Research Boulder, Colorado.

Dr. A.F.Treshnikov - Effects of sea-ice
Academician G.I.Marchuk - adjoint methods applied to
                          climatic variations

  c) To come to the University of Washington
     (Seattle, Washington)

Dr. A.F.Treshnikov - Modelling of ice dynamics

  d) To come to Stanford University, California

Academician Mustel - Problems of solar activity and climate

2.3 Subgroup 3. Assessment of past climates on the basis of the analysis of natural objects and data

2.3.1. Scientific Cooperation

A. Century program (0 - 100 years before present)

This will focus on climatic changes in the period of modern instrumental data, including aerological data for the past 20 or 30 years, and will attempt to document the most recent trends of climate together with environmental changes which may have causal connections with such trends.

  a) Exchange of data, as raw (unsmoothed) time series:

  (i) Indices of atmospheric circulation intensity
      and patterns in the Northern Hemisphere.
      - Update of Dzerdzeevskii circulation-type
        epoch data by the Institute of Geography,
        Moscow; (Ya. L. Rauner, suggested cooperating scientist).
      - Updated series of coefficients of empirical orthogonal functions of monthly mean

sea-level pressure (by NOAA Environmental
Data Service, Washington, D.C.; J.M.Mitchell,
jr., suggested cooperating scientist).

(ii) Regional and hemispheric-scale average values
of monthly average climatic parameters in Nor-
thern Hemisphere.

- Climatological surface air temperature in
the form of digitized grid-point values on
I IBM-compatible magnetic tape for the period
1881 to at least 1960 together with related
publications (by Main Geophysical Observato-
ry, Leningrad; Ye.P.Borisenkov, suggested
cooperating scientist)

- Updated series (since 1958) of hemispheric
circulation statistics, including zonal and
meridional wind indices, free-air tempera-
ture, geopotential height, specific humidi-
ty, kinetic energy, fluxes of heat and mo-
mentum (by NOAA/CFDL, Princeton,N.J.;
A.Oort, suggested cooperating scientist).

- Complete digitized "World Weather Records"
temperature, precipitation and pressure da-
ta, by stations, on magnetic tape for the
period from beginning of record at each
station to at least 1960 together with re-
lated publications (by NOAA Environmental
Data Service, Washington D.C.; J.M.Mitchell,
jr. suggested cooperating scientist).

(iii) Exchange climatological data concerning the
energy balance of the earth-atmosphere sys-
tem and its geographical distribution.
The USSR side would contribute surface-based
data on the components of heat balance. The
US side would contribute satellite-based data
on the planetary heat balance, including
cloudiness.

(iv) Oceanologic indices of seasonal and year-to-
year variations of conditions in the North
Atlantic Ocean.
- Measures of geographical distribution of
ocean-surface temperature and heat content
of mixed-layer of ocean (by Institute of
Oceanology, Moscow; V.G.Kort, suggested
cooperating scientist).
= Data on oceanic conditions, including month-
ly average surface temperatures and their
variations over a period of many years, for
all available locations in the ocean (by
NOAA Environmental Data Service, Washington,
D.C.; J.M.Mitchell, Jr., suggested coopera-
ting scientist).

b) Millenium Program (0 - 1,000 years before present)
This will document in greater detail the course of
global climate change in earlier centuries, thus
lending perspective to the course of climate in the
20th century in the context of historical events
including the "Little Ice Age".

c) Ice-age History Program (0-30,000 years before
present, and older)
This will help improve the understanding of the
extremes of climate, and of the nature of the tran-
sitions of climate, both within and following a ma-
jor glacial event on earth; and to clarify the geo-
graphical pattern of conditions and events during
each phase of the glaciation and deglaciation, as
needed to evaluate the accuracy of climate simulation
models.

2.3.2 Exchange of Data

a) Tree-ring widths
- un-normalized ring-width series from replicated
trees in each of 11 or 12 subpolar sites in USSR,
from the Finland border eastward to the Kamchatka
Peninsula (by the Lithuanian Academy of Sciences,

Kaunas, Dr. Bitvinskas, suggested cooperating sci-
entist; and by the Botanical Institute, Leningrad,
Dr. Lovelius, suggested cooperating scientist).
- Ring-width series and detailed information concer-
ning transfer functions relating ring-width series
to climate, for any or all of the more than 49
available sites in North America as desired (by
University of Arizona, Tucson; H.C.Fritts, sugges-
ted cooperating scientist).

b) Exchange paleoclimatographic data acquired according
to the plans approved at the Paleoclimatographic Con-
ference described in 2.3.3.

2.3.3 Action Proposed.

a) Conference on paleoclimatography:* a technical confe-
rence to be held approximately June, 1975; to be or-
ganized to accomplish the specific objectives listed
below, and to include as many of the cooperating sci-
entists listed below as possible, in addition to
other scientists.

Country	Institution	Suggested Participants
USSR	Institute of Geography, Moscow	M.I.Neustadt, N.S.Chebotareva, M.G.Grossvald, V.P.Gruchuk, A.A.Velichko, N.A.Khotinsky
USSR	Institute of Geology, Moscow	K.N.Nikiforova, N.V.Kind, R.E.Giterman, E.Korenova, M.A.Pavzner
USSR	All-Union Geological Institute (VSEGEI) Leningrad	I.I.Krasnov
USSR	Institute of Geology, Novosibirsk	V.N.Saks
USSR	Institute of Geology, Murmansk	S.A.Strelkov
US	Lamont-Doherty Geological Observatory, New-York	W.S.Broecker, N.Opdyke

* To be held in Russia. See page 25.

US	University of Wisconsin	J.Kutzbach
US	Brown University, Providence, Rhode Island	T.Webb, J.Imbrie
US	University of Minnesota	H.Wright
US	Yale University, New Haven, Connecticut	M.Davis
US	US Geological Survey	D.Adam, E.Leopold
US	University of Maine	G.Denton
US	Ohio State University	T.Hughes
US	University of Washington	S.Porter

The objectives of the Conference are as follows:

- To plan for the exchange of data on C-14 dated ice-sheet moraines from as many locations as possible in the U.S. and USSR (especially Siberia).

- To plan for the exchange of historical palynological data (samples, pollen counts, C-14 dates, and pollen diagrams) from C-14 dated stratigraphic sections located as widely as possible in the U.S. and USSR including areas well south of areas covered by glacial ice during the Quaternary.

- To plan for the exchange of modern pollen data (samples, pollen counts, geographic locations) from sites distributed as widely as possible in the U.S. and USSR

- To exchange statistical transfer-function techniques designed to extract rainfall and seasonal temperature estimates from fossil pollen data.

- To assess the C-14 dating facilities needed to accomplish the first and second objectives in the U.S. and USSR, and to make appropriate recommendations to insure the needed support.

- To formulate a research plan for acquiring continuous stratigraphic sections (both pollen diagrams from lake cores and soil sequences) covering all or significant

portions of the Brunhes Magnetic Epoch (the past 690.000 years) in the U.S. and USSR at a number of widely-distributed sites.

b) Conference on paleoclimatic modelling: a technical conference to be held in the U.S. in June 1976 or thereabouts, designed to exchange results of experiments simulating selected past climates.

(i) U.S. scientists will present results of numerical experiments aimed at simulating ice-age climates at the last glacial maximum using general circulation models (NCAR, Boulder, Colorado; J.Williams, W.Washington, and R.G.Barry, suggested cooperating scientists. National Science Foundation's IDOE/CLIMAP Project Scientists and other institutions as appropriate)

(ii) USSR scientists will present results of climate-modelling experiments carried on by the Institute of Geography, Moscow (I.P.Gerasimov, suggested cooperating scientist) and by the Main Geophysical Observatory, Leningrad (M.I. Budyko, suggested cooperating scientist).In addition, information on ice-age climate in the oceans will be presented by the scientific staff of the Institute of Oceanology, Moscow (A.Lysitsin, suggested cooperating scientist) and other institutions as appropriate.

c) Exchange of scientific personnel.
Each country shall have the right to arrange for working visits of up to a total of 6 man-months duration per year by up to 3 scientists. Soviet institutions open to visitation shall include the Institutes of Geography, Geology, and Oceanology in Moscow, the All-Union Geological Research Institute in Leningrad and in Novosibirsk, and the Siberian Branch of the USSR Academy of Sciences in Novosibirsk. U.S. institutions open to visitation shall include those listed under 2.3.3. above.

PROJECT 2. JOINT STUDIES OF THE EFFECTS OF POLLUTION OF THE ATMOSPHERE ON CLIMATE

2.4. Subgroup 4. Monitoring atmospheric constituents and assessment of their effects on climate

2.4.1. Scientific cooperation

a) At present, the USA has 4 baseline stations and 10 regional stations with 2 additional baseline stations planned for the future. The USSR has 1 baseline station and 5 regional stations. It is desirable to enlarge the network of stations and to expand their geographical location. The respective networks should be expanded as soon as feasible and largely completed by 1980.

b) Both countries will provide for the accomplishment of measurements within the WMO program (aerosol chemistry based on the study of the atmospheric turbidity, rain chemistry and CO_2). Additional measurements beyond these minimum requirements are also being made others are planned.

c) Both countries should develop methods of measurement and systems of calibration for carbon dioxide, ozone, and atmospheric turbidity (and other optical properties) at the baseline stations and exchange the experience gained and the data from such work.

(i) The US would provide a surface ozone measuring system for operation at a USSR remote Observatory. The exchange would be phased as follows:

1974 - one electrochemical concentration cell system

1975-76 - one chemiluminescence (ethylene reaction) system.

One precision ozone generator.

D) Meeting of Experts to Prepare Data Base of the Recent Climate

This group would recommend how the data base discussed in Section 2.2.2 should be structured, the parameters to ve included, their resolution in space and time, the level of processing of the data and their statistical treatment. The group would also recommend how such a data base should be compiled and an appropriate division of responsibility with due recognition of the need for full international cooperation to achieve global data sets and the role of GARP in compiling global data sets in connection with GARP experiments.

The group would also recommend procedures and formats for the full exchange of all data and analyses that comprise the data base for the present climate.

A meeting of 6 to 8 specialists will be organized in the United States within the next 12 months. Dr. Oort will organize the meeting.

E) Meeting of Experts on Quaternary Glaciation

This group would study the distributions and changes of ice and climatic zones in the USSR during the recent upper-quaternary glaciations. Prof. Imbrie would help organize the meeting which should be held in the USSR during 1975.

3.4. Long Duration Working Visits of Scientists

It is desirable to have scientists from each country visit the other country for periods of 6 to 12 months to work on problems connected with climatic variation.

3.4.1 The U.S. would like to issue invitations to Soviet scientists to visit the following U.S. institutions for 6 to 12 month period.

(a) To come to the Geophysical Fluid Dynamics Laboratory of NOAA in Princeton, New Jersey: (1) to study climate sensitivity and stability; (2) to work on radiation effects of particulates; (3) and to study numerical integration methods.

(b) To come to the National Center for Atmospheric Research
in Boulder, Colorado to study adjoint methods of climatic
perturbation and to study effects of sea ice on climate.

(c) To come to the University of Washington in Seattle to
study models of ice dynamics.

(d) To come to Stanford University to study the analysis
of variations of temperature and pressure fields in the
upper and lower atmosphere during solar disturbances.

The USSR would like to issue invitations to U.S. scientists
to visit the following USSR institutions for 6 to 12 months pe-
riods.

(a) To come to the Computing Center of the Siberian Branch
of the Academy of Sciences to study numerical modelling
of climate.

(b) To come to the Main Geophysical Observatory of the Hy-
drometeorological Service in Leningrad to work on prob-
lems of measuring minor constituents in the atmosphere.

(c) To come to the Arctic and Antarctic Research Institute
in Leningrad to work on problems of polar areas as they
effect climate.

(d) To come to the Hydrometeorological Center in Moscow
to work on problems of climate prediction and documen-
tation.

3.4.2. For the purpose of expediting the exchange of climatic
data, a scientist from the USSR should visit the US
National Climatic Center in Asheville, N.C. At this
time lists of available climatic data and information
will be exchanged on magnetic tape formats. The Soviet
scientist will bring an example of a tape prepared in
the USSR and will be supplied with an example of a tape
prepared in the U.S. This visit would probably last
one month and would be carried out during the next year.

LIST OF PARTICIPANTS

U S A

1. Dr.W.N.HESS — Principal Delegate, NOAA/Environmental Research Laboratories
2. Dr.S.C.CORONITI — CIAP/Department of Transportation
3. Prof.R.CHARLSON — University of Washington
4. Dr.E.S.EPSTEIN — NOAA/Environment Monitoring and Prediction
5. Mr.J.O.FLETCHER — National Science Foundation
6. Dr.A.J.GROBECKER — CIAP/Department of Transportation
7. Prof.J.IMBRIE — Department of Geological Sciences, Brown University
8. Dr.C.E.LEITH — National Center for Atmospheric Research
9. Dr.J.M.MITCHELL — NOAA/Environmental Data Services
10. Dr.S.M.OLENICOFF — National Science Foundation
11. Mr.D.H.PACK — NOAA/Air Resources Laboratory
12. Mrs.F.SETTLE — NOAA/Environment Research Laboratories
13. Dr.J.SMAGORINSKY — NOAA/Geophysical Fluid Dynamics Laboratory
14. Prof.J.M.WILCOX — Institute for Plasma Research, Stanford University

U S S R

15. Prof.Ye.P.BORISENKOV — Principal Delegate, Voeikov Main Geophysical Observatory, Leningrad
16. Prof.M.E.BERLYAND — Voeikov Main Geophysical Observatory, Leningrad
17. Dr.I.I.BORZENKOVA — Voeikov Main Geophysical Observatory, Leningrad
18. Prof.M.I.BUDYKO — Voeikov Main Geophysical Observatory, Leningrad
19. Dr.A.A.BUZNIKOV — Leningrad State University, Leningrad
20. Prof.O.A.DROZDOV — Voeikov Main Geophysical Observatory, Leningrad
21. Prof.L.S.GANDIN — Voeikov Main Geophysical Observatory, Leningrad
22. Dr.A.A.GRIGORIEV — Leningrad State University, Leningrad
23. Dr.G.G.GROMOVA — Hydrometeorological Centre, Moscow
24. Dr.G.P.GUSHCHIN — Voeikov Main Geophysical Observatory, Leningrad

25. Dr.I.L.KAROL   Voeikov Main Geophysical Observatory, Leningrad

26. Mr.Yu.E.KAZAKOV   Chief Administration of the Hydrometeorological Service of the USSR, Moscow

27. Dr.G.M.KREKOV   Institute of Atmospheric Optics, Tomsk

28. Dr.V.F.LOGINOV   All-Union Research Institute of Hydrometeorological Information, Obninsk

29. Dr.V.P.MELESHKO   Voeikov Main Geophysical Observatory, Leningrad

30. Dr.V.V.MIKHNEVICH   Institute of Applied Geophysics, Moscow

31. Prof.E.P.MUSTEL   Hydrometeorological Centre,Moscow

32. Dr.V.V.PENENKO   Computer Centre,Novosibirsk

33. L.R.RAKIPOVA   Voeikov Main Geophysical Observatory, Leningrad

34. Dr.B.I.SAZONOV   Voeikov Main Geophysical Observatory Leningrad

35. Prof.S.V.SOLONIN   Leningrad Hydrometeorological Institute, Leningrad

36. Dr.V.Ya.SERGIN   Pacific Geographic Institute of the AS USSR, Vladivostok

37. Prof.M.E.SHVETZ   Voeikov Main Geophysical Observatory, Leningrad

38. Dr.V.D.STEPANENKO   Voeikov Main Geophysical Observatory, Leningrad

39. Dr.A.F.TRESHNIKOV   Arctic and Antarctic Research Institute, Leningrad

40. Dr.R.F.USMANOV   Hydrometeorological Centre, Moscow

41. Dr.O.B.VASILIEV   Leningrad State University,Leningrad

42. Dr.K.Ya.VINNIKOV   Voeikov Main Geophysical Observatory, Leningrad

43. Prof.M.I.YUDIN   Voeikov Main Geophysical Observatory, Leningrad

APPENDIX C

CARTOGRAPHIC ANALYSIS OF THE CHANGING TIME-SPACE PATTERNS IN THE HOLOCENE POLLEN RECORD OF NORTHEASTERN NORTH AMERICA

Bernabo, J. Christopher and Thompson Webb III, Dept. of Geol. Sci., Brown University, Providence, R.I.   02912

Fifty-two radiocarbon-dated cores from the northeastern U.S. and southern Canada provided the basis for mapping the distribution of selected pollen types at each 1,000-year interval during the Holocene. The sequence of these maps traces the development of the vegetation over the last 11,000 years. Three types of maps were constructed: isopollen maps, difference maps, and isochrone maps. Isopollen maps show the distribution of a pollen type at a given time and are contoured with lines of equal pollen frequency (isopolls). Difference maps are generated by subtracting successive isopollen maps and illustrate the areas of changing pollen frequencies over selected time intervals. The production of both of these map types converts a set of geographically disjunct time-series (the pollen diagrams) into synoptic regional patterns. Recognition of these patterns is crucial to deciphering the ecological and climatic significance of the pollen record. Isochrone maps show the "range limits" of specified pollen types at 1,000-year intervals and are useful in studying differential migration rates.

Analysis of the maps indicates that the major climatically-induced vegetational changes of the Holocene culminated by 8,000 YBP. Prior to that time, changes in pollen distribution were closely related to the position of the ice margin. By ca. 8,000 YBP, the modern configuration of vegetational formations was established with conifer-hardwood forests in the northern Great Lakes, deciduous forests to the south and prairie to the west. Changes in the position of the ecotones and in the composition of the pollen record were smaller in scale after ca. 8,000 YBP than before. Other features of the Holocene pollen record depicted by the maps are the rapid decline of spruce pollen, and westward extension of pine pollen (see figure) and the mid-Holocene prairie expansion and retreat.

Many lines of independent evidence reveal that the early Holocene was a period of rapid climatic change. Comparison of the behavior of different pollen types shows that spruce, pine and oak responded rapidly to these changes. The shifting distribution of these genera appears to be a useful monitor of the changing macroclimate. Certain other genera, however, such as chestnut, hickory and beech responded sluggishly, migrating northward and westward gradually over much of the Holocene. Ecological factors, other than climate, such as soil development, reproductive strategy and competitive interactions probably played a dominant role in controlling the distribution of these genera (see M. B. Davis, this volume).

The mapping of pollen data on a sub-continental scale emphasizes the broad geographic patterns in the vegetation which are indicative of macroclimate and changes in its state. Pollen maps also serve to summarize the pollen record in a graphic form that is readily comprehensible to a wide range of interested Quaternary scientists, outside palynology.

PALYNOLOGICAL EVIDENCE OF ECOTONAL MIGRATIONS IN EASTERN NORTH AMERICA

Webb, Thompson III and J. Christopher Bernabo, Dept. of Geo. Sci.,
Brown University, Providence, R.I. 02912

Pollen data monitor the vegetation through time and space. Comparison of maps of the modern pollen data with maps of the modern vegetation show the patterns of formations and forest types to be represented clearly within the pollen data (Webb, 1974, Ecology). Transitions (or ecotones) between forest types or formations are therefore evident upon the maps of modern pollen and are recorded by changes in the relative abundances of certain pollen types from one region to the next. The relative weightings of the ecological factors controlling the positions of the various ecotones is as yet unspecified. Study of the behavior of these ecotones through time, however, may help in defining the relative importance of the various ecological factors.

Bernabo et al. (see Abstract, this volume) have prepared maps showing the distribution of pollen types at selected times during the Holocene in eastern North America. The sequence of these maps from 11,000 YBP to present shows that ecotones change in character and position through time. On the modern maps of pollen distribution, the ecotone between deciduous forests and conifer-hardwood forests in the Midwest (which coincides with the "tension zone" there) is marked by the south to north change from the dominance of oak pollen to the dominance of pine pollen. This same change in pollen dominance can be used to trace the position of this ecotone in the past (see figure). Early in the Holocene, the position of this ecotone changes drastically, probably in direct response to the fast changing climatic patterns of that period. After 8,000 YBP, the position of this ecotone remains relatively stable but the composition of the pollen spectra continue changing on both sides of the boundary as new pollen types appear. This relative stability in the location of the ecotone is in direct contrast to the changing composition of the formations it separates, and this stability reflects a different weighting of ecological factors that control the ecotone's position from the weighting of the factors controlling community composition. Probably the former is mainly controlled by macroclimatic factors, e.g., air mass patterns, whereas the latter is controlled largely by edaphic, biological and small-scale climatic factors.

Isochrones of a pollen-defined ecotone in 10^3 years. Present position along 6-7 contour.

ON THE USE OF TREE RINGS, POLLEN AND MARINE PLANKTON IN RECONSTRUCTING PAST CLIMATES

Webb, Thompson III and Douglas R. Clark, Dept. of Geol. Sci., Brown University, Providence, R.I. 02912

Large collections of tree ring, pollen and marine plankton data enable the study of eco-climatic interactions over wide geographic areas, and over long time spans. Multivariate statistical techinques like those used by Fritts (Abstract, this volume) provide a means for obtaining quantitative estimates of past climates from the biological data. When enough cores containing one type of these data are available in a region, a map depicting the estimated climate can be prepared for selected time-intervals within the age range of the cores and such paleoclimatic maps are now becoming available.

.One remarkable feature of these three types of data is that they complement each other in their time resolution and their length of record. In the data sets suitable for mapping, the annually spaced tree rings give decade by decade summaries of the past 500 years; pollen data that are generally sampled in 200-year intervals give 1,000 year by 1,000 year summaries of the past 12,000 years; and marine plankton data sampled in ca. 3,000-year intervals give 10,000 year by 10,000 year summaries of the past 150,000 years.

Overlap between the three different data sets also occurs. For instance, pollen from annually laminated lake-sediments can have the time precision of tree rings, and tree ring sequences can be extended the length of Holocene pollen records. This overlap is important because 1) where two data sets occur in one locality, climatic estimates derived from one data set can be used to verify the estimates from another data set, and 2) where the two data sets occur in different localities, possible teleconnections in the climates of the two regions can be studied. An opportunity of the latter type exists given the mapped pollen records of eastern North America (Bernabo et al., Abstract, this volume) and the mapped foraminifera data of Ruddiman (Abstract, this volume) in the North Atlantic. These two data sets provide a basis for studying the interaction between climatic patterns over land and sea during the early Holocene.

In eastern North America between 10,000 and 9,000 B.P., the "late-glacial boreal forest" largely disappears and high values of pine pollen appear within 100 km of the Laurentide ice margin. This change indicates a steepening of the climatic gradient south of the ice margin and creates a meteorological situation conducive to strong westerly flow near the ice margin. This proposed circulation pattern supports the one hypothesized by Ruddiman to explain the distribution of sea-surface temperatures in the North Atlantic at 9,300 B.P.

PALEOECOLOGICAL SIGNIFICANCE OF THE CHANGING PATTERNS IN THE HOLOCENE POLLEN RECORD OF NORTHEASTERN NORTH AMERICA

Bernabo, J. Christopher and Webb, Thompson, III, Department of Geological Sciences, Brown University, Providence, R.I. 02912

Maps showing the distribution of pollen from the major tree genera and herbs, for each 1,000 yr. interval during the Holocene, were constructed using 52 radiocarbon-dated cores. The production of such maps converts a set of geographically disjunct time series (the pollen diagrams) into synoptic regional patterns. Examining the dynamics of these patterns is crucial to interpreting the climatic and ecological significance of the pollen record. Analysis of the maps indicates that the major climatically-induced vegetational displacements of the Holocene occurred before 8,000 YBP. Prior to that time, changes in pollen distribution were closely related to the position of the shifting ice margin. By 8,000 YBP the modern configuration of vegetational regions was established with mixed conifer-hardwood forests in the northern Great Lakes, deciduous forests to the south and prairie to the west. Changes after 8,000 YBP were smaller in scale and altered the areal extent not the gross configuration of the vegetational regions. Comparison of the behavior of different genera reveals that spruce, pine and oak responded rapidly to changing environmental conditions and are useful paleoclimatic indicators. However, hickory, hemlock, beech and chestnut gradually migrated northward during much of the Holocene. The slower climatic responses of these genera makes their paleoenvironmental message unclear.

Oral ☐   Discussion ☐   Symposium ☐   _____

(title of symposium)*

Speaker _____

Indicate authors who are not GSA members _____ : T. Webb

Percentage of paper previously presented __O__, where and when _____

Other abstracts submitted to this meeting (an individual may author or co-author no more than two uninvited abstracts and may present only one paper) _____

Only 2-x-2-inch slides can be projected, and only one screen will be available during a technical session.

Employer's permission to publish, if required, is the author's responsibility.

____ will be available to serve as a co-chairman for a technical session on or concerning _____

Temporary address of senior author, with dates (for correspondence purposes) _____

CLASSIFICATION

Specify one. If more than one category is appropriate, indicate order of preference by numbers. Be as specific as possible.

crystallography
geochemistry

geochronology

geology
  archeologic
  economic

  education
  engineering
  environmental
  general
  historical
  lunar
  marine

  mathematical
1 Pleistocene
  structural

geomorphology

geophysics

geomagnetism
geoscience information
hydrogeology
mineralogy

paleontology
  micro
  invertebrate
  vertebrate

petrology
  igneous
  metamorphic
  sedimentary
planetology

sedimentology
stratigraphy
tectonics
volcanology

OTHER Paleoecology
2   palynology

D-1

APPENDIX D

D-1

Direct correlation of marine and

terrestrial paleoclimates: palynological

and foraminiferal evidence from two marine

cores off Cape Hatteras.

William L. Balsam
Department of Geological Sciences
Brown University
Providence, Rhode Island   02912

and

Linda E. Heusser
Department of Biology
New York University
Tuxedo, New York   10987

The relationship between oceanic and continental paleo-
climates is unclear; adequate data on air/sea interaction being
available only for the past several hundred years. Fine scale
correlation of marine and terrestrial paleoclimatic data is
limited by the often brief and abrupt nature of climatic change
and by errors associated with age-dating techniques. In order
to overcome these correlation problems, we analyzed marine and
terrestrial climatic indicators from identical samples in C^{14}
dated marine cores thereby obtaining a direct correlation of
climatic events.

Both pollen and planktonic foraminifera were analyzed from
cores V24-1 and V26-176 taken from the continental rise off the
mouth of Chesapeake Bay (Figure 1). The sediment in these cores
is an olive-gray lutite with coarse fraction (weight greater than
63 microns) rarely exceeding 10 percent. The carbonate content
of the cores fluctuates from 4 to 32 percent with higher values
being characteristic of the last 8000 years (Figure 2). In
these cores C^{14} dates were used in conjunction with carbonate
minima and maxima and floral datum planes to establish a down-
core chronology and correlation between cores.

Pollen concentration varied from 800 to 12,000 grains/gram
thereby permitting identification of a significant number of
pollen grains in each sample. Pollen diagrams from these marine

cores exhibit the following features (Figures 3 and 4). Boreal vegetation was replaced by thermophilous forest elements about 10,000 YBP, the late glacial/Holocene boundary. Glacial (before 10,000 YBP) pollen assemblages are characterized by pine, spruce, fir, and herbs, which in the Early Holocene are supplanted by a pine-oak assemblage in which hemlock is briefly abundant. Pollen from deciduous trees continues to increase in abundance until 3500 YBP when oak declines and pine re-expands. Comparison of these marine pollen diagrams to pollen diagrams from the Chesapeake drainage basin demonstrates that pollen assemblages from these marine cores accurately reflect the timing of vegetation changes on land.

Planktonic foraminifera were analyzed using transfer function F13 to obtain down-core estimates of paleo-oceanographic parameters. In addition, because these cores are located in waters influenced by the Gulf Stream, certain species of planktonic foraminifera were used as Gulf Stream indicators. In particular, 10 percent or greater abundance of _Globogernoides_ _sacculifer_ appears to be restricted to the average position of the warmest part of the Gulf Stream. Down core estimates of winter temperature indicates that the maximum temperature in this area was reached about 8000 YBP (Figure 5). Furthermore, the increased abundance of _G_. _sacculifer_ suggests that this temperature maxi-

mum is associated with the movement of the Gulf Stream. From 8000 YBP to the present, both cores exhibit generally decreasing surface temperatures (Figure 5) related to the increased import- ance of the subpolar fauna (Figure 6). Today the dominant faunal assemblage at the site of both cores is subpolar (Figure 7). However, V26-176 is very close to the boundary between the sub- polar and tropical/gyre margin assemblage. Before 8000 YBP, the two cores show a diachronous pattern of estimated winter temper- ature changes related to the complex interaction of the subpolar and tropical fauna (Figure 6).

Comparison of foraminifera-derived temperature estimates and pollen fluctuations in these cores suggests that in the area studied, terrestrial climatic events lag somewhat behind changes in the ocean (Figure 8). However, terrestrial changes appear to be more closely related to variations in slope water temperature than to Gulf Stream migrations.

Figure Captions

Figure 1. Sketch map showing location of cores and study area. The locations and depths of the cores are as follows: V24-1, $36^{\circ}30$'N lat., $73^{\circ}30$'W long., 3012 m.; V26-176, $36^{\circ}03$'N lat., $72^{\circ}23$'W long., 3942 m.

Figure 2. Down core variations in calcium carbonate and correlation points indicated by C (carbonate correlation), D (radiocarbon date), and F (floral datum). The correlation points are as follows: C_1, carbonate maxima C^{14}-dated at about 8000 YBP in both cores; C_2, carbonate minima co-occurring with F_2; C_3, first carbonate maxima below C_2; D_1, 8050 $\pm$ 250 C^{14} YBP; D_2, 12,400 $\pm$ 350 C^{14} YBP; D_3, 3830 $\pm$ 140 C^{14} YBP; D_4, 8180 $\pm$ 200 C^{14} YBP; F_1, floral datum 1; F_2, floral datum 2; F_3, floral datum 3 (floral datum planes identified on Figures 3 and 4). Letter with identical subscripts are judged to be the same age and are used to establish time planes between the cores.

Figure 3. Pollen diagram from core V24-1 showing relative frequency of selected pollen taxa. Note that the percent scale for pollen taxa changes; Pinus, Quercus, and Picea are at one scale and the remaining taxa at another.

Figure 4.   Pollen diagram from core V26-176 showing relative

   frequency of selected pollen taxa.   Variations in percent

   scale are the same as for Figure 3.

Figure 5.   Down core estimates of winter sea-surface temperature

   (TW) and percent abundance Globogerinoides sacculifer.

Figure 6.   Down core variations in selected planktonic foramini-

   feral assemblages.   Factor loading value indicates the re-

   lative importance of each assemblage in a sample.

Figure 7.   Present distribution of dominant assemblages off Cape

   Hatteras, North Carolina.

Figure 8.   Direct correlation of land/sea climatic changes.
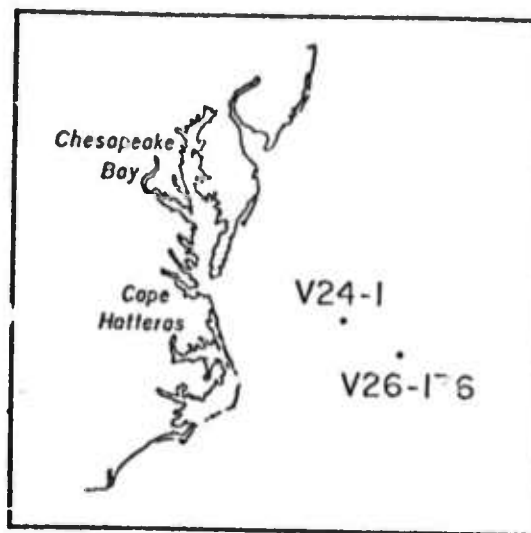
Figure 1.
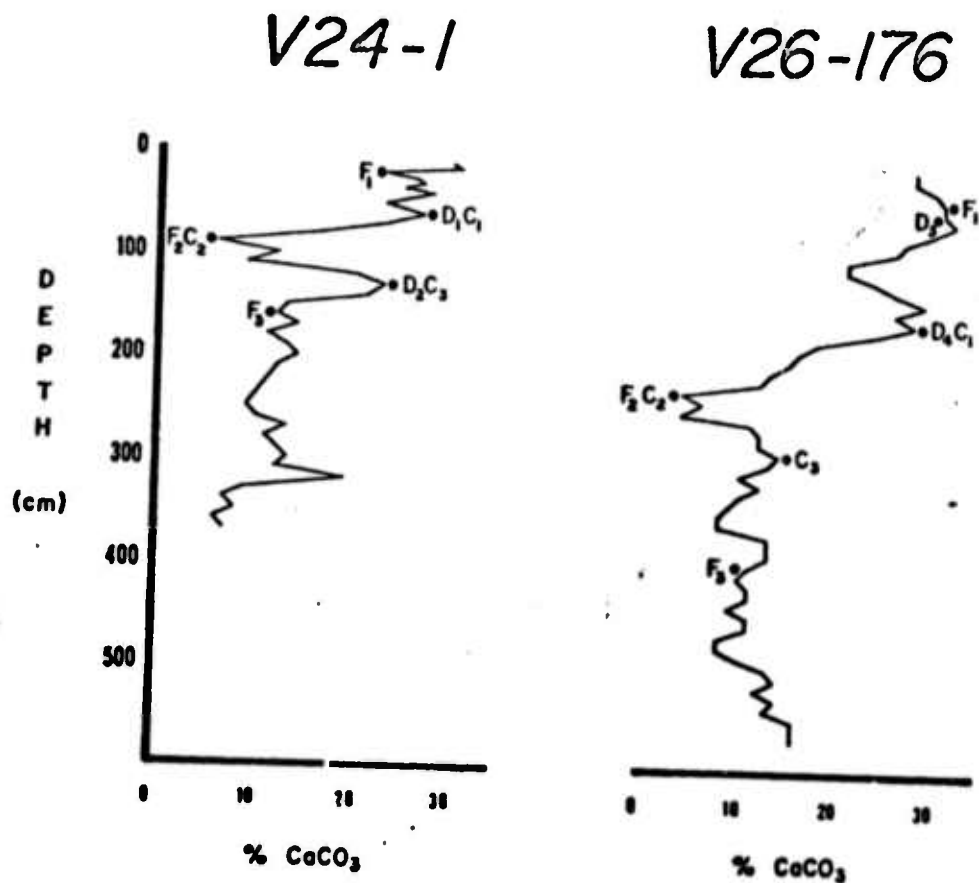
Figure 2.
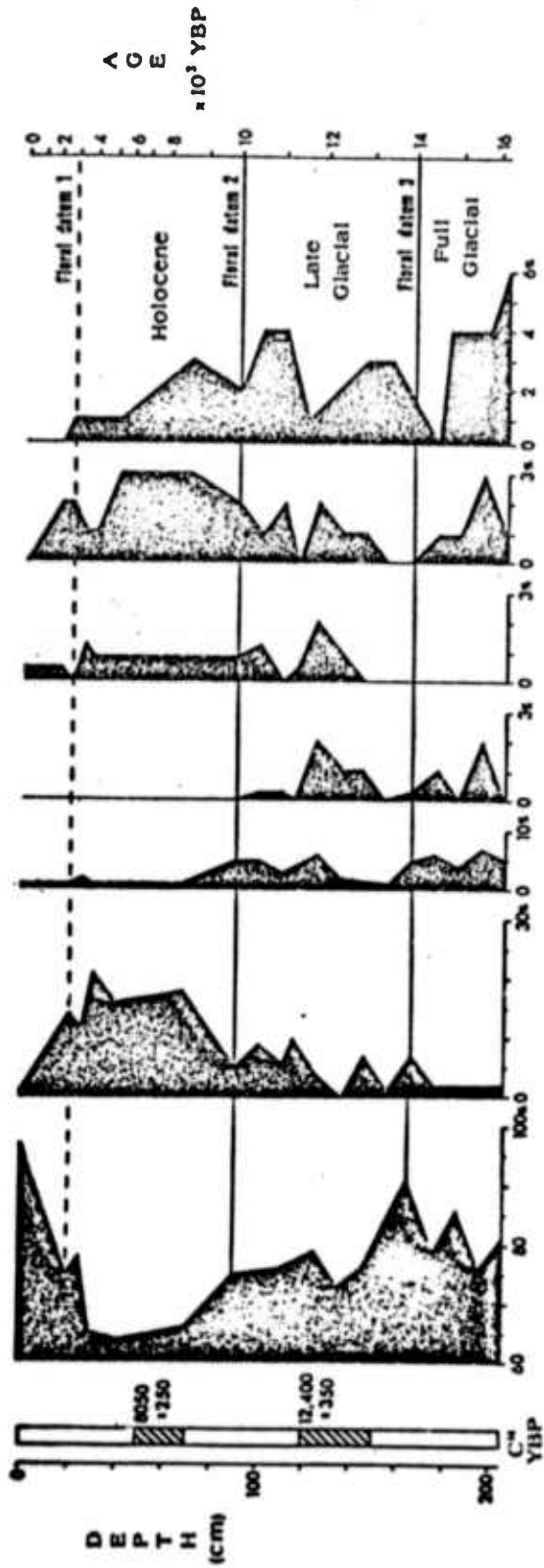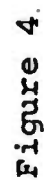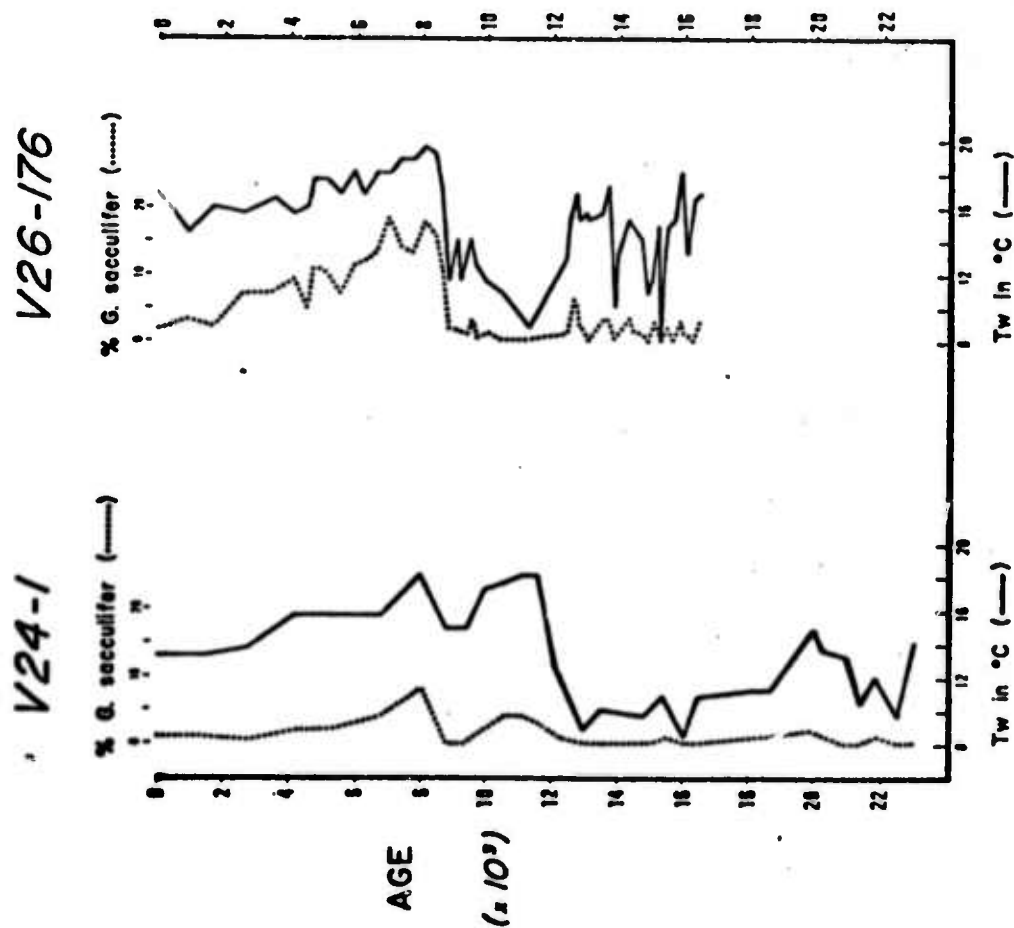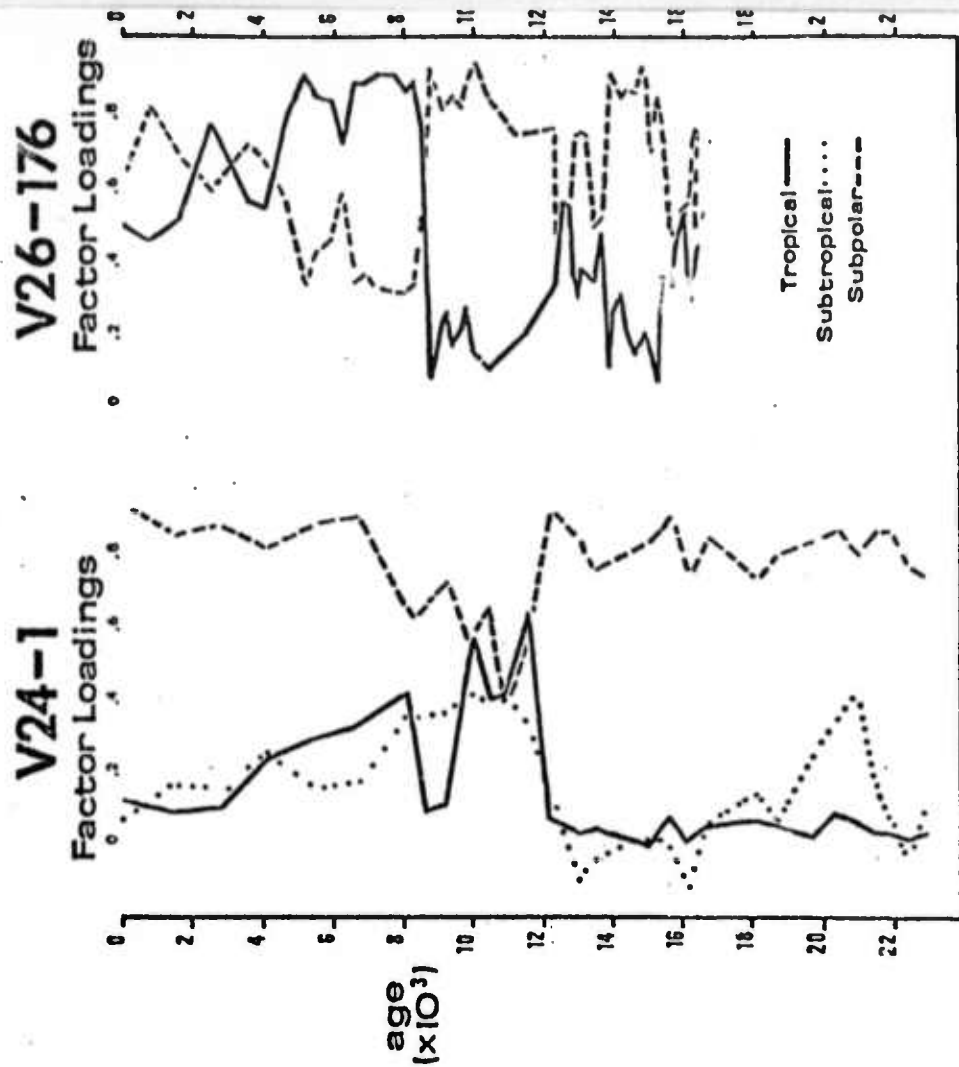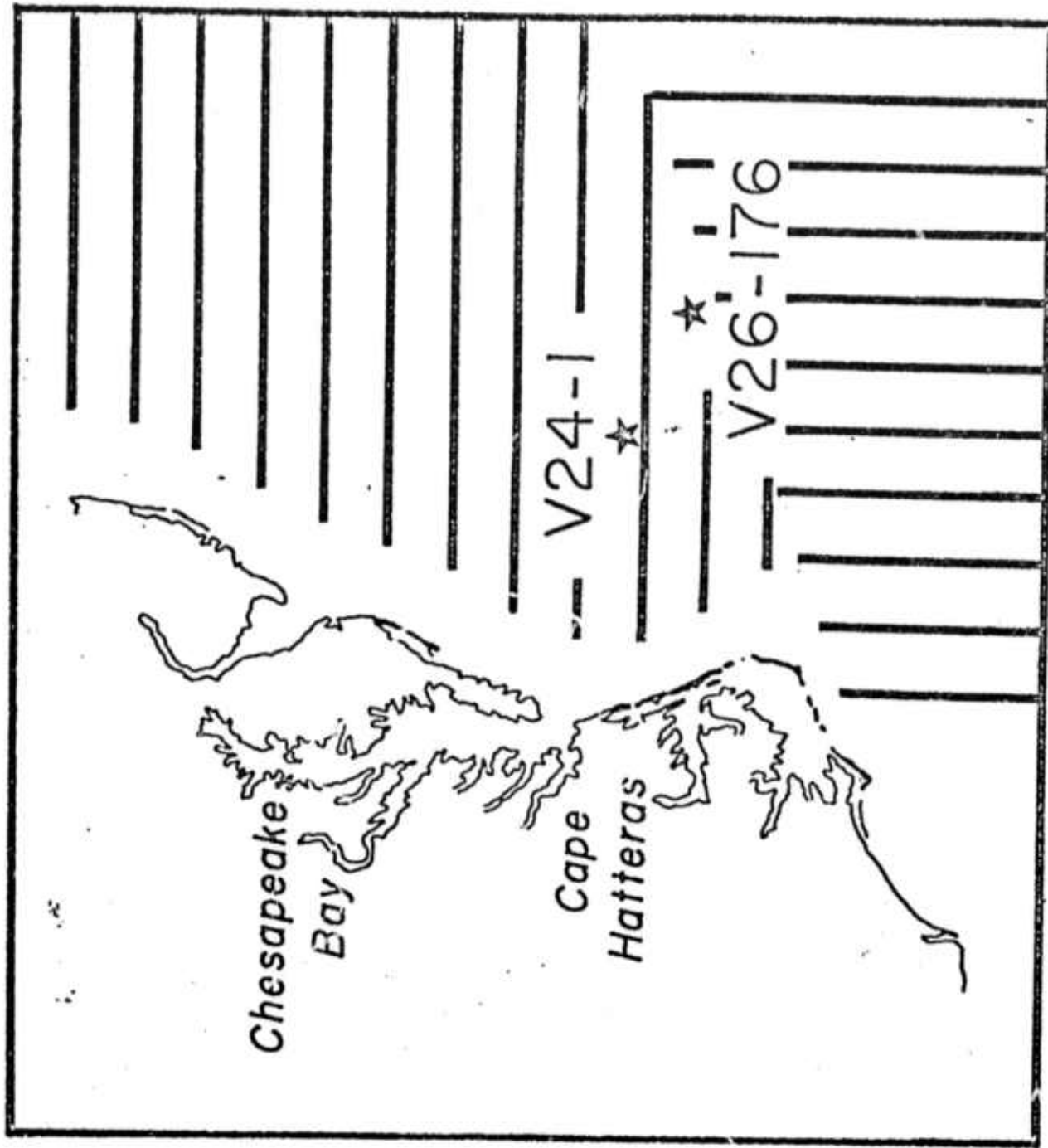
Figure 3

Figure 4.

Figure 6
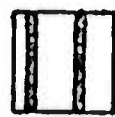

Figure 5

DOMINANT ASSEMBLAGE

Subpolar

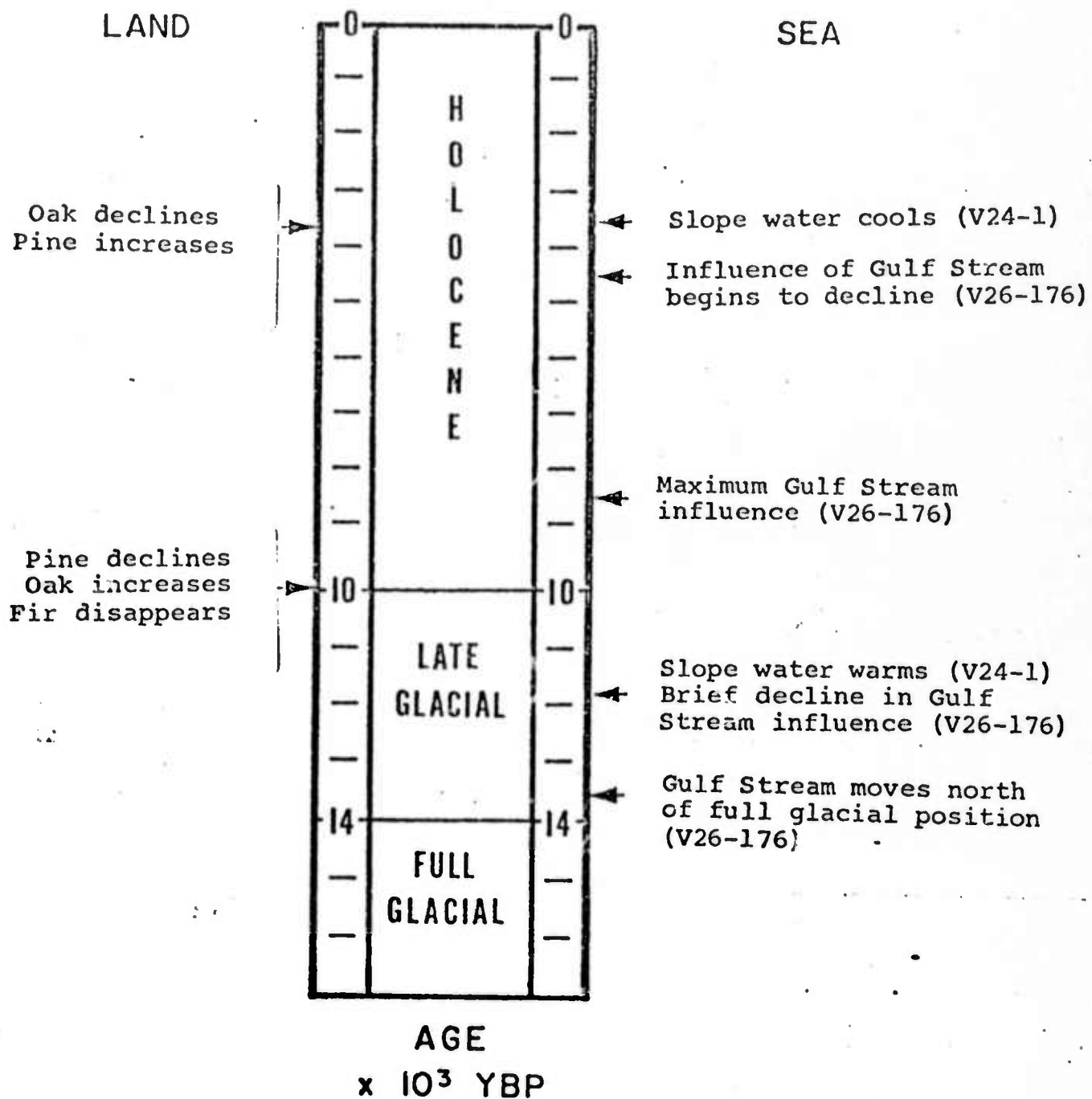Tropical and
Gyre Margin

Figure 7

Figure 8

CHANGES IN CLIMATIC REGIME
NEAR CAPE HATTERAS, N.C.

APPENDIX E

Calibrating micropaleontological data in climatic terms:

a brief review

John Imbrie

Thompson Webb III

CLIMAP, Brown University, Providence, R.I., U.S.A.   02912

ABSTRACT

Transfer functions are empirical equations for making quantitative estimates of past atmospheric and oceanic conditions from paleontologic data. They are calibrated on a set of geographically-distributed observations which record both the modern climate and the biotic response to climate as reflected in paleontological samples. The technique has been used on tree rings and pollen as well as on planktonic microfossils (including foraminifera, coccoliths, and radiolaria). Down-core applications in deep-sea Quaternary sediments yield time series reflecting local changes in seasonal temperatures and salinity. When applied to samples from a chronostratigraphic horizon, transfer functions yield synoptic charts of past climates. In this form paleontological data are readily interpretable by meteorologists and physical oceanographers, and can be entered as boundary conditions into numerical models of climate.

INTRODUCTION

Since the early years of the last century, when Esmark and Agassiz made their astonishing discovery of ancient ice ages, the story of past climates has been elaborated in considerable detail. This story has been documented from a wide variety of sources, ranging from moraines which fix the position of ancient ice bodies to studies of fossil pollen and plankton which provide panoramas of past continents and oceans. Yet these findings remain unexplained in terms of verified theories of climatic change. Why?

Several basic reasons may be cited, not least among them the extraordinarily complex structure of the climate system. The heart of the problem, however, is the difficulty of achieving an effective interplay between climatic theory and paleoclimatic data. This difficulty results from a mismatch in the time-space structure of the observational and theoretical realms. Where dynamic theory is strong -- i.e., in its ability to explain synoptic patterns of climate in terms of atmospheric and oceanic circulation -- the corresponding sets of paleoclimatic data on spatial patterns of climate are sparse. And where kinetic theory is weak -- i.e., in its ability to analyze climatic change -- we have an abundance of geologic time series documenting climatic change. This mismatch is now being overcome,

firstly by translating geological observations into quantitative estimates of those climatic variables which physical theories use and predict; and secondly, by producing synoptic maps of the paleoclimatic estimates in areas where samples are densely arrayed and adequately dated.

Transfer-function techniques, which are the subject of this paper, are playing a major role in this task. These techniques use multivariate statistical procedures to extract quantitative estimates of air and sea-surface properties from the fossil records. If the stratigraphic coverage permits, these quantitative estimates can be mapped for selected time intervals during the Quaternary (Fritts et al., 1971; McIntyre et al., 1975). In this form the data can then be used either as boundary condition for running mathematical models of the global circulation; or as a basis for verifying the results of such models. Although still in their infancy, these powerful models are the main focus of a growing scientific effort to understand past, present, and future climates.

This paper summarizes some of the proceedings of a conference on transfer functions held at the University of Wisconsin, U.S.A., April 3-5, 1974, and funded by special grants from the ARPA Climate Dynamics Program and the National Science Foundation's International Decade of Ocean

Exploration. The initiative for the Wisconsin conference stemmed from a 1973 Report of SCOR Working Group 40, which recommended a conference that would review the various models, analyze their compatibility, assess their strengths and weaknesses, evaluate the need for further methodological work, and produce reports to promote wider use and understanding of these techniques.

The objective of this paper is to make available to the community of scientists studying the oceanic micro-paleontological record an overview of the subject of transfer functions. We give references to previous work; describe briefly the model used in deriving transfer functions from micropaleontologic data; and outline an algebraically homogeneous set of methods which have been used to apply to the model. In another paper (Webb et al., in preparation) we flesh out the algebraic details of these methods, present the results of a series of algebraic experiments designed to explore their properties and make specific recommendations for research to solve some basic problems.

PREVIOUS WORK

Transfer function techniques were first applied to marine plankton data by Imbrie and Kipp (1971), to terrestrial pollen data by Webb and Bryson (1972), and to tree ring data by Fritts et al., (1971). Recent applications

and improvements of these techniques of special interest

to marine micropaleontologists appear in articles by

Gardner and Hays (1975), Hecht and Kipp (1974), Imbrie et

al., (1973), Kipp (1975), Lozano and Hays, (1975), McIntyre

et. al., (1975), Prell et al., (1975), Sachs (1973), and

Sancetta et al., (1973).

THE BASIC MODEL

Definitions

Let the matrix X be a defined set of biological re-

sponse properties, e.g., relative abundances of organisms

measured over a defined realm of space and time $(x,y;t)$.

Let C be a set of physical variables of climate, either

marine or atmospheric, measured over the same time-space

realm and assumed to be causally related to X. Examples

include seasonal sea-surface and air temperatures and sea-

sonal values of precipitation and salinity. Let D be a

set of other physical variables of the system which to-

gether with C completely determine X. D often includes

such difficult-to-measure factors as nutrient-availability,

soil-texture, dissolution, and anthropogenic disturbance.

Thus the model is completely deterministic, in the sense

that the observations in X are explained as responses to

the ambient field of physical variables. No allowance is

made for the operation of random factors, or of historical

influences (relict biotas, migration patterns, etc.).

Then, if $D = 0$ or is constant, the system consists of X, C, and a set of <u>ecological response functions</u> R_e:

(1) $X = R_e$ (C).

If D is nonconstant, we must consider the <u>total response function</u> R_t:

(2) $X = R_t$ (C:D).

A fundamental problem of paleoclimatology is to find a set of <u>transfer functions</u> $\emptyset$ such that C can be estimated given X, as follows:

(3) $C = \emptyset$ (X)

In practice $\emptyset$ is obtained by direct empirical methods and not by inversion of R_e or R_t. Although such inversion procedures would have many theoretical advantages, and should be explored further, research to date has uncovered many practical problems.

The class of empirical solutions to equation (3) that will be discussed here take the form

(4) $C = XB$

in which B is a matrix of empirical <u>calibration functions</u>. Thus B represents one subclass of $\emptyset$, and relates to a monitoring system with <u>domain</u> X and <u>range</u> C. The X and C used to derive the calibration functions B are the <u>calibration data-set</u> (X_m, C_m). The X to which the calibration functions are applied is the application data set (X_f). X_m is a spa-

tial array of observation points over the modern land sur-
face or seabed; X_f is a temporal array of fossil data, e.g.
micropaleontological data from a core.

As defined in Imbrie et al., (1973, p. 11), equations
that relate biological indices to various properties of the
ocean or atmosphere "may be termed transfer functions in
the sense that they are a means of processing one time-
varying signal (or set of signals) in a core, to yield
another signal consisting of paleotemperature estimates."
All of the paleontological transfer functions written to
date either are, or can be reduced to, simple linear trans-
formations symbolized as B in equation (4). To emphasize
this fact, and to encourage the application of more soph-
isticated procedures, we have chosen to define B as a set
of calibration functions and to consider B as a subset of
transfer functions (∅).

If it were possible to derive ∅ deductively from a
process-oriented model based on ecological first princi-
pals, the predictive power of this model would be free of
many of the problems encountered in its use (see Webb et
al., in prep.). Given the current state of ecological
theory, however, the empirical approach represents the only
practical solution to equation 3, and we are, therefore,
stuck with its limitations and have no choice but to con-

front the problems arising from its application.

Major Assumptions

When $\emptyset$ is applied to data on fossils several assumptions must be made, as outlined in Imbrie and Kipp (1971, p. 79) and in Webb and Bryson (1972, p. 74). The four most important are:

1) That the ecosystem under study has not changed significantly during the interval represented by the application data set X_f. Specifically, the assumption is made that the species recorded in X_m are essentially the same biological entities as those in X_f, and that they have not changed significantly their ecological responses to individual physical properties of the environment. This assumption is a highly restricted form of the principle that the present is the key to the past and requires that contemporary spatial patterns can be used to interpret changes through time.

2) That the biota represented by X are systematically related to the physical attributes of the medium in which they dwell.

3) That the variables recorded in C are, or are linearly related to, ecologically significant aspects of the ocean or the atmosphere.

4) That mathematical equations representing linear

combinations of biological taxa can reflect the biotic
responses to physical changes adequately enough to yield
accurate calibration functions.

ALGEBRAIC METHODS

Several multivariate methods can be used in the cal-
culation of the calibration functions. These techniques
include multiple regression, stepwise multiple regression,
principal components analysis plus multiple regression
(Imbrie and Kipp, 1971), canonical correlation analysis
(Webb and Bryson, 1972), and distance coefficients plus
regression (Hecht, 1973). These techniques are described
and their results are compared in Webb et al. (in prep.)
and in Hecht and Kipp (1974).

APPLICATIONS

Transfer functions were first applied to planktonic foraminifera in a deep-sea Caribbean core (Imbrie and Kipp, 1971). Since then the technique has been used on a number of planktonic taxa in Quaternary cores raised from the floors of many oceans. Down-core applications include studies of radiolaria from the North Pacific (Sachs, 1973a and 1973b), Eastern Pacific (Moore, 1973), and Antarctic (Hays et al., 1975; Lozano and Hays, 1975); studies of planktonic foraminifera from the Norwegian Sea (Kellogg, 1975), North Atlantic (Sancetta et al., 1973), and Caribbean (Prell and Hays, 1975; Prell et al., 1975), Equatorial Atlantic (Gardner and Hays, 1975), Gulf of Mexico (Brunner and Cooley, 1975), and Pacific (Luz, 1973); and studies of coccoliths from the North Atlantic (Roche et al., 1975), and Pacific (Geitzenauer et al., 1975). In addition, work in progress by N. Maynard, L. Burckle, C. Sancetta, and H. Schrader prove that Quaternary diatoms can be interpreted by transfer function techniques.

Most of the studies just cited give transfer functions for estimating three different physical properties of the surface water: summer temperature, winter temperature, and salinity. Although these properties are highly

correlated within modern ocean basins, downcore results
show considerable independence. Whereas thermal and
salinity estimates show a high positive correlation at
mid- and high-latitude sites in the North Atlantic during
the past 130,000 years (Figure 1), a negative correlation
exists between surface-water temperatures and salinities
estimated at many low latitude sites (Figure 2). The
positive correlation in the higher latitudes is attributed
to changes in circulation pattern (McIntyre et al., 1972):
cold, low-salinity water penetrates southward during gla-
cial phases and replaces warm, higher-salinity water.
The decrease in salinity associated with this southward
penetration of polar waters apparently exceeds the increase
that, for the average ocean, must result from the growth
of ice sheets. The negative correlation between tempera-
ture and salinity estimates observed at many low-latitude
sites (Figure 2) must be due to some combination of two
effects which would act in the direction of increasing
salinity during a glacial phase: the global build-up of
continental ice, and local increases in the evaporation-
precipitation ratio (Prell et al., 1975).

How accurate are paleoclimatic estimates derived from
transfer functions? The first step in answering this

fundamental question is to evaluate how transfer functions perform on various sets of data reflecting modern conditions. After calculating the standard error of estimate in the calibration data set (Figure 3), the performance of the transfer function can be tested on modern samples representing different geographic areas. Kipp (1975), for example, has carried out such a test for a transfer function calibrated on a North Atlantic data set. When applied to 60 samples from the South Atlantic sea bed, the estimates are accurate within the previously calculated confidence interval. Although such a result does not in itself validate down-core estimates, it does encourage belief in estimates derived from late-Quaternary Atlantic sediments.

The second step in verifying down-core estimates is to screen out any sample whose taxonomic composition or dissolution level lies outside the range represented in the calibration data set. Such samples represent conditions for which no modern analog is known.

The third step in the procedure for verifying down-core estimates is the comparison of the results of any transfer function with independent paleoclimatic estimates. Concordant estimates encourage belief; discordant estimates

discourage belief, but may raise important questions for further research.

One class of independent estimates results from the application of transfer functions to different biotic groups. Another class of independent estimates is based on isotopic methods. Although applications of the oxygen-isotope paleotemperature method must now take into account the discovery by Shackleton and Opdyke (1973) that the water-composition effect dominates the thermal effect, these authors outline an alternate procedure for obtaining temperature estimates. When this alternative procedure was applied to one Caribbean core (Shackleton and Opdyke, 1973), the result was concordant with the previous estimate made by transfer function methods (Imbrie et al., 1973). Clearly, much more work of this kind remains to be done.

After completing the testing of the estimates just described, the transfer function techniques can be used in constructing paleoclimatic maps. In this form paleoenvironmental data are readily interpretable by meteorologists and physical oceanographers, and as discussed above can be entered as boundary conditions into

numerical models of climate. One goal of the International

Decade of Ocean Exploration's CLIMAP Project is to prepare

temperature and salinity charts for past oceans and arrange

for their analysis by numerical models. An example of such

a map is given in Figure 4, where the sea-surface tempera-

ture for the North Atlantic Ocean during an ice-age summer

is reconstructed.

Perhaps the most important feature of this ice-age re-

construction is the demonstration of a structured, synoptic

pattern of climatic change. Portions of the subtropical

gyre, for example, were actually slightly warmer during the

glacial phase than they are today. Elsewhere the anomaly

is negative; but while the Caribbean cools only 1°C to 2°C,

the temperature change in many higher latitudes reaches and

in some places exceeds 10°C. By themselves, however, neither

the small changes in the low latitudes nor the large changes

in mid-latitudes provide an adequate record of the climatic

change. Any dynamic explanation of the change in the North

Atlantic must address the entire synoptic pattern. It is

here that transfer functions can make their greatest con-

tribution to the study of paleoclimates: normalizing to a

common temperature scale paleoenvironmental inferences

based on different groups of fossils.

ACKNOWLEDGMENTS

Imbrie and Webb

E 15

REFERENCES

BRUNNER, C. A., and COOLEY, J. F.

1975 Circulation in the Gulf of Mexico during the last
glacial maximum 18,000 years ago. Geol. Soc.
America, Memoir no. 145, Cline and Hays eds., in
press.

FRITTS, H. C., BLASING, T. J., HAYDEN, B. P., and KUTZ-
BACH, J. E.

1971 Multivariate techniques for specifying tree-growth
and climate relationships for reconstructing anoma-
lies in paleoclimate. J. App. Meteorol., vol. 10,
pp. 845-864.

GARDNER, J. V., and HAYS, J. D.

1975 The eastern equatorial Atlantic: sea-surface tem-
perature and circulation responses to global clima-
tic change during the past 200,000 years. Geol.
Soc. America Memoir no. 145, Cline and Hays, eds.,
in press.

GEITZENAUER, K., ROCHE, M., and MCINTYRE, A.

1975 Modern Pacific coccolith assemblages: derivation
and application to Late Pleistocene paleotempera-
ture analysis. Geol. Soc. America Memoir no. 145,
Cline and Hays, eds., in press.

HAYS, J. D., LOZANO, J., SHACKLETON, N. J., and IRVING, G.

1975   An 18,000 year B.P. reconstruction of the Atlantic

and western Indian sectors of the Antarctic Ocean.

Geol. Soc. America Memoir no. 145, Cline and Hays,

eds., in press.

HECHT, A. D.

1973   A model for determining paleotemperatures from

planktonic foraminiferal assemblages. Micropaleon-

tology, vol. 19, p. 68-77.

HECHT, A. D. and KIPP, N. G.

1974   Experiments in transfer function paleoecology:

application to Pleistocene paleotemperatures. Pro-

gram 1974 Annual Meeting, Geol. Soc. America, p.

787 (Abstract).

IMBRIE, J. and KIPP, N. G.

1971   A new micropaleontological method for quantitative

paleoclimatology: application to a Late Pleisto-

cene Caribbean core. Turekian, K. K., ed., The Late

Cenozoic Glacial Ages: New Haven, Conn., Yale Univ.

Press, p. 71-182.

IMBRIE, J., VAN DONK, J., and KIPP, N. G.

1973   Paleoclimatic investigation of a Late Pleistocene

Caribbean deep-sea core: comparison of isotopic and

faunal methods.   Quaternary Research, vol. 3, no. 1, p. 10-38.

KELLOGG, T. B.

1975   Late Quaternary climatic changes: Evidence from Norwegian and Greenland Sea Deep-sea cores.   Geol. Soc. America Memoir no. 145, Cline and Hays, eds., in press.

KIPP, N. G.

1975   New Transfer function for estimating past sea-surface conditions from the sea-bed distribution of Planktonic Foraminiferal assemblages in the North Atlantic.   Geol. Soc. America Memoir no. 145, Cline and Hays, eds., in press.

KUKLA, J.

1970   Correlations between loesses and deep-sea sediments, Geologiska Föreningens i Stockholm Förhandlingar 92 p. 148-180.

LOZANO, J., and HAYS, J. D.

1975   The relationship of radiolarian assemblages to sediment types and physical oceanography in the Atlantic and western Indian sectors of the Antarctic Ocean. Geol. Soc. America Memoir no. 145, Cline and Hays, eds., in press.

LUZ, B.

1973 Stratigraphic and paleoclimatic analysis of Late
      Pleistocene tropical southeast Pacific cores (with
      an Appendix by N. J. Shackleton). Quaternary Re-
      search, vol. 3, no. 1, p. 56-72.

MCINTYRE, A., KIPP, N. G., BE, A. W. H., CROWLEY, T. J.,
KELLOGG, T., GARDNER, J. V., PRELL, W., and RUDDIMAN, W. F.

1975 The glacial North Atlantic 18,000 years ago: A
      CLIMAP reconstruction. Geol. Soc. America Memoir
      no. 145, Cline and Hays, eds., in press.

MCINTYRE, A., RUDDIMAN, W. F. and JANTZEN, R.

1972 Southward penetrations of the North Atlantic Polar
      Front: faunal and floral evidence of large-scale
      surface water mass movements over the last 225,000
      years. Deep-Sea Research, vol. 19, p. 61-77.

MOORE, T. C., JR.

1973 Late Pleistocene-Holocene Oceanographic changes in
      the northeastern Pacific. Quaternary Research, vol.
      3, no. 1, p. 99-109.

PRELL, W. and HAYS, J. D.

1975 Late Pleistocene faunal and temperature patterns of
      the Colombia Basin, Caribbean Sea. Geol. Soc. Amer-
      ica Memoir no. 145, Cline and Hays, eds., in press.

PRELL, W., GARDNER, J. V., BÉ, A. W. H., and HAYS, J. D.

1975 Equatorial Atlantic and Caribbean faunas, tempera-
      tures, and circulation: interglacial versus glacial.
      Geol. Soc. America Memoir no. 145, Cline and Hays,
      eds, in press.

ROCHE, M. B., MCINTYRE, A. and IMBRIE, J.

1975 Quantitative paleo-oceanography of the Late Pleisto-
      cene-Holocene North Atlantic: coccolith evidence.
      Saito, T. and Burckle, L., eds., Micropaleontology,
      in press.

SACHS, H. M.

1973a Late Pleistocene history of the North Pacific:
       evidence from a quantitative study of Radiolaria
       in core V21-173. Quaternary Research, vol. 3, p.
       89-98.

SACHS, H. M.

1973b North Pacific radiolarian assemblages and their
       relationship to oceanographic parameters. Quater-
       nary Research, vol. 3, p. 73-88.

SANCETTA, C., IMBRIE, J., and KIPP, N. G.

1973 Climatic record of the past 130,000 years in north
      Atlantic deep-sea core V23-82: Correlation with
      the terrestrial record. Quaternary Research, vol. 3,
      no. 1, p. 110-116.

SHACKLETON, N. J. and OPDYKE, N. D.

1973   Oxygen isotope and paleomagnetic stratigraphy of
       Equatorial Pacific core V28-238:   oxygen isotope
       temperatures and ice volumes on a 10^5 year and
       10^6 year scale.   Quaternary Research, vol. 3, no.
       1, p. 39-55.

WEBB T., III, and BRYSON, R. A.

1972   Late and postglacial climatic change in the northern
       midwest U.S.A.:   quantitative estimates derived from
       fossil pollen spectra by multivariate statistical
       analysis.   Quaternary Research, vol. 2, p. 70-115.

WEBB, T., III, IMBRIE, J. and CLARK, D. R.   in prep.
       Calibrating micropaleontological data in climatic
       terms: a critical review, MS in prep., to be sub-
   mitted to Quaternary Research.

Figure Captions

Figure 1. Faunal indices Ts, Tw, and S vs depth in
North Atlantic core V23-82. Thick bars indicate 80% con-
fidence intervals for analytical precision of indices.
Horizontal lines indicate samples lacking coccoliths
(McIntyre et al., 1972). Pattern in column indicates sam-
ples with high mineral detritus content in the > 149 μm
fraction: diagonal pattern 10-20% of sample, solid pattern
> 20% of sample. Age of 800 cm sample estimated as 127,000
years. From Sancetta et al. (1973) Figure 2.

Figure 2. Plots of foraminiferal index T_w, δ O18 in
‰, and foraminiferal index S versus depth for Caribbean
core V12-122. The foraminiferal indices are defined by a
set of transfer functions F3 and scaled to be unbiased
estimates of winter surface water temperature (°C) and
average surface salinity (‰), respectively. The faunal
index curves are plots of a running mean of three samples.
Letters T through Z designate Ericson zones defined on the
basis of presence or absence of G. menardii. Letters A through
G designate a correlation with the climatic cycles of Kukla
(1970) defined from the soil sequence of Central Europe.
From Imbrie et al. (1973) Figure 3, with modifications.

Figure 3. Observed values of winter sea-surface tem-
perature versus estimates calculated by transfer function

F13 for 191 North Atlantic sea-bed samples of planktonic

foraminifera.   (a) Scatter diagram with 80% confidence in-

tervals indicated by dashed lines.   (b) Geographic distri-

bution of the residuals. $|\Delta|$ is the absolute value of the

difference between observed and estimated temperatures.

The standard error is 1.165^{O}C. The mean deviation is indi-

cated for areas with more than two points in which more

than half of the residuals are of the same sign. From Kipp

(1975), Figure 28.

Figure 4.   Sea-surface temperatures in the North

Atlantic Ocean.   (a) Summer temperatures today in ^{O}C.   (b)

Summer temperatures 18,000 years ago in ^{O}C, as estimated

by foraminiferal and coccolith transfer functions.   Solid

contours are controlled by micropaleontological data in

about 100 cores.   Sea-ice margin identified from paleonto-

logic and sedimentologic characteristics.   Note that this

reconstruction shows substantial cooling in northern waters,

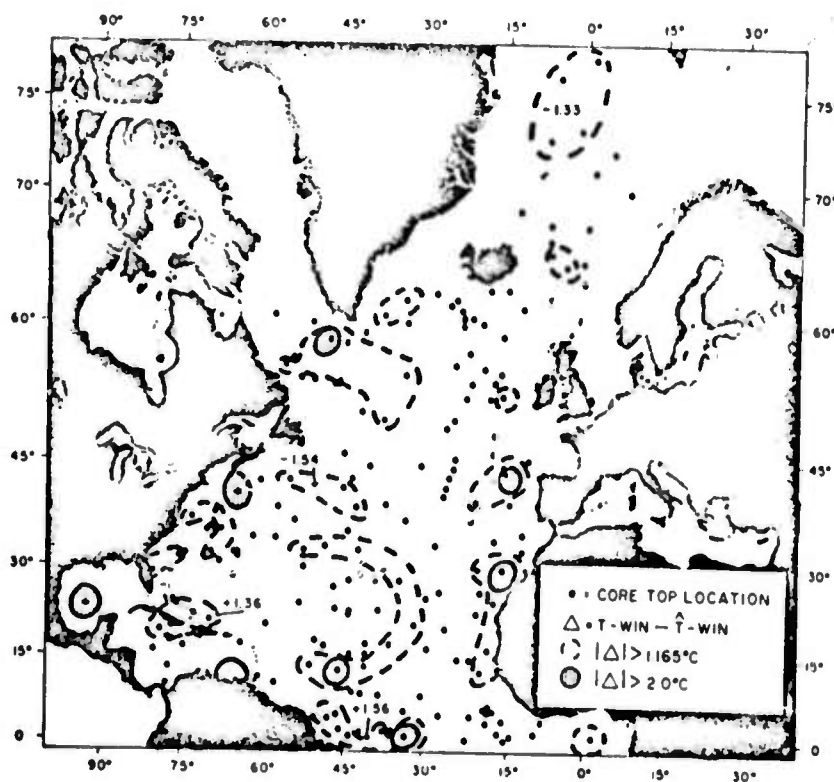with little or no change in the subtropics.   From McIntyre
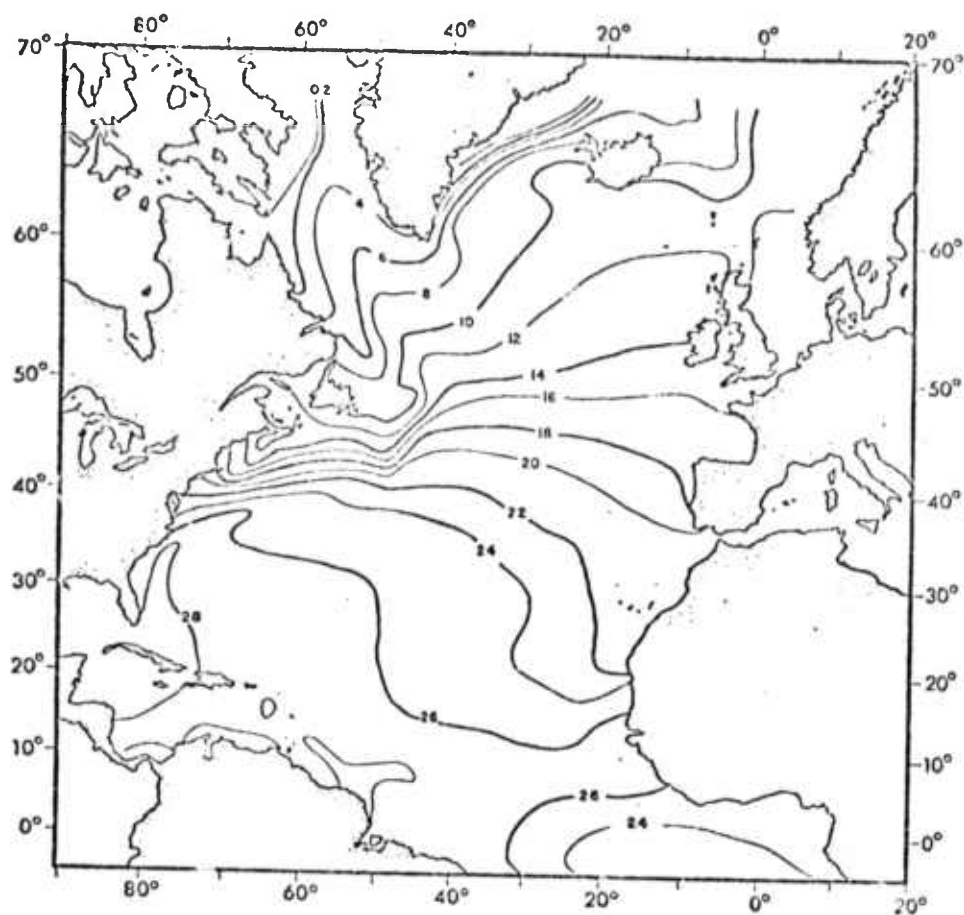
et al. (1975).

E23
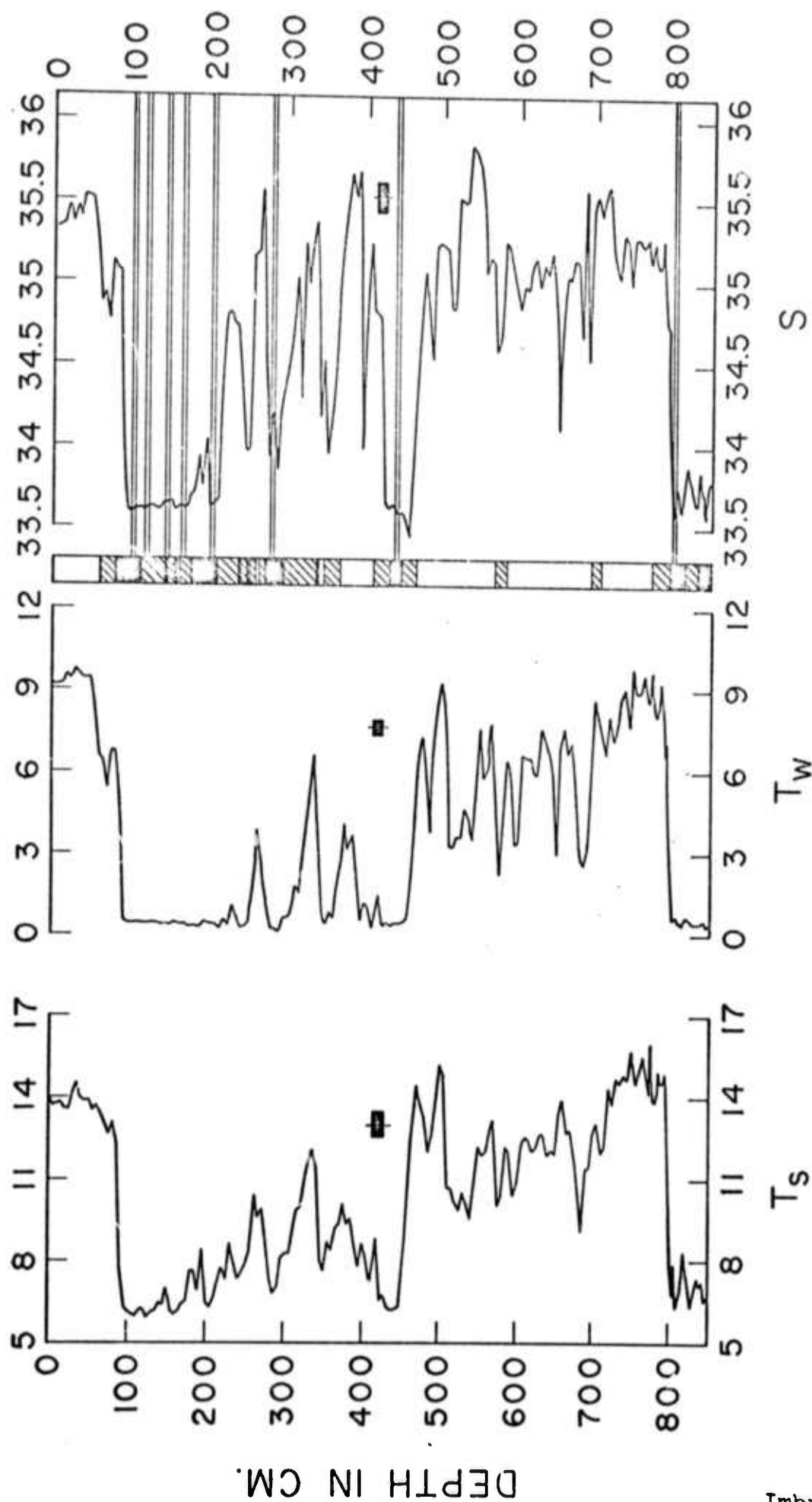
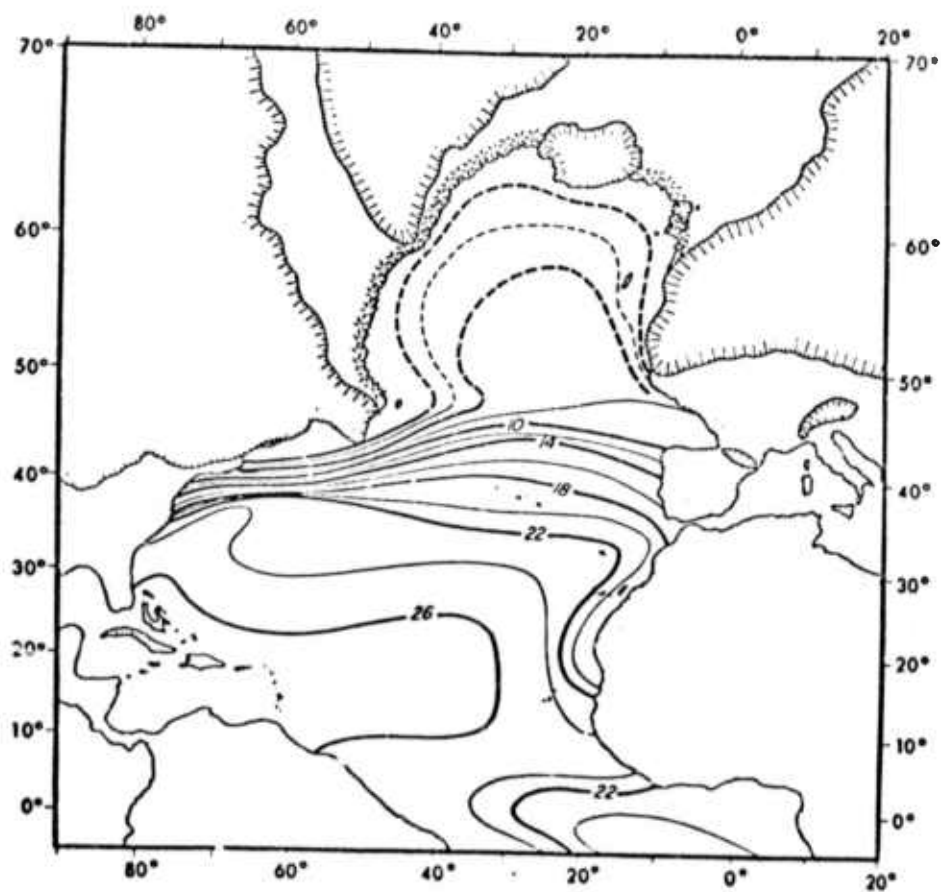Imbrie and Webb
Fig. 1
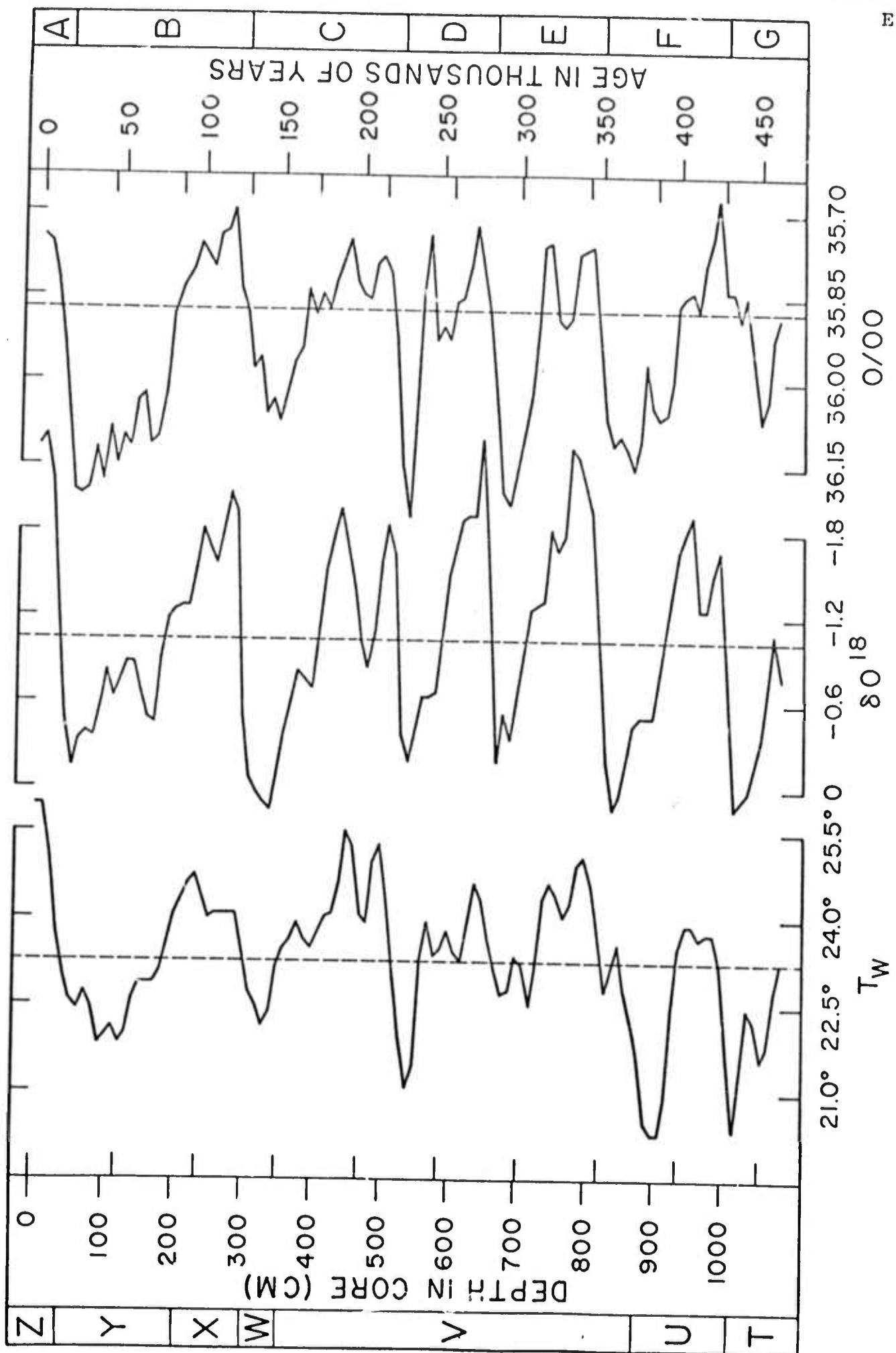
Imbrie and Webb
Fig. 2

E24

A

B

Imbrie and Webb
Fig. 3
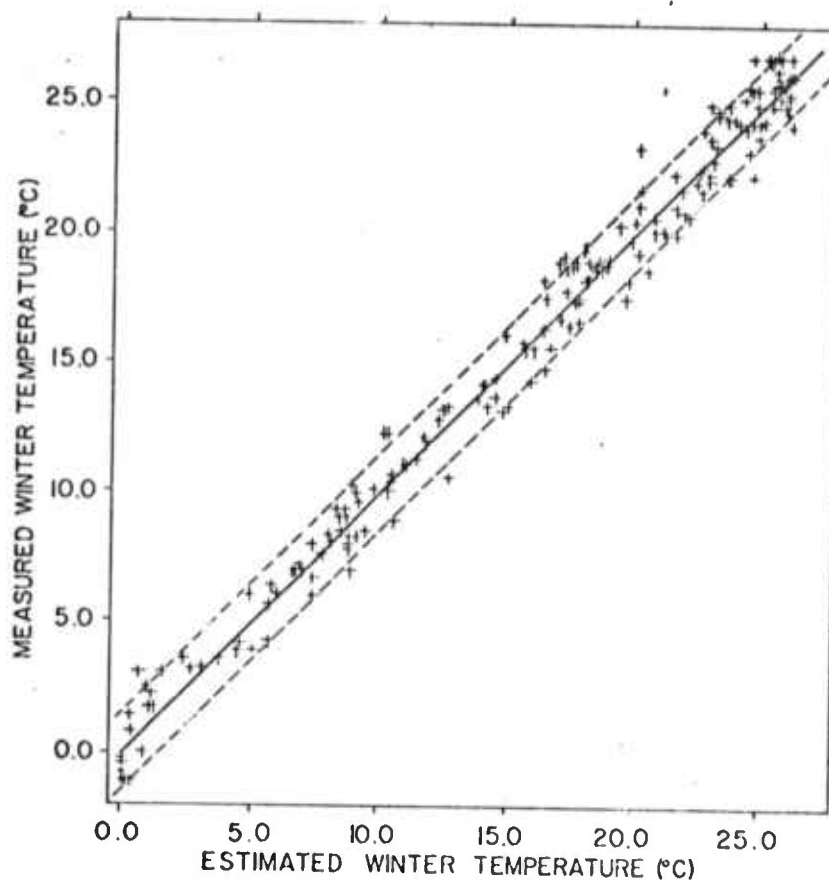
Imbrie & Webb
Fig. 4a

Imbrie & Webb
Fig. 4b